AERO DIGEST

AVIATION ENGINEERING

JUNE 1956

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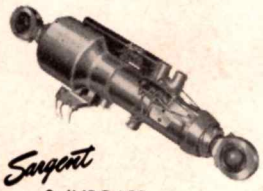

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Sargent RUDDER
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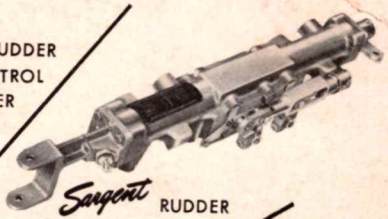

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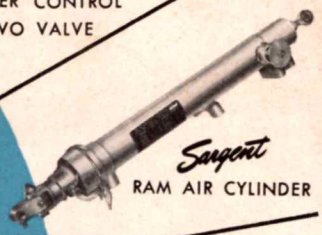

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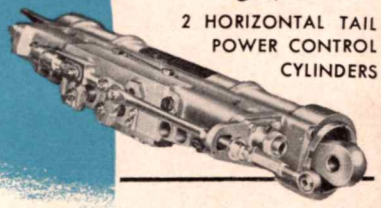

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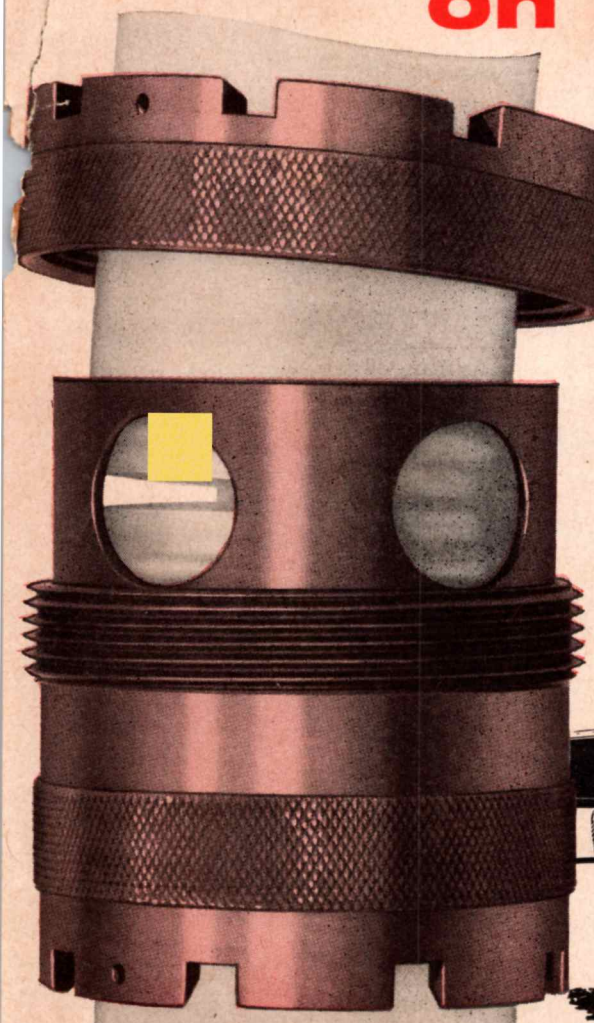
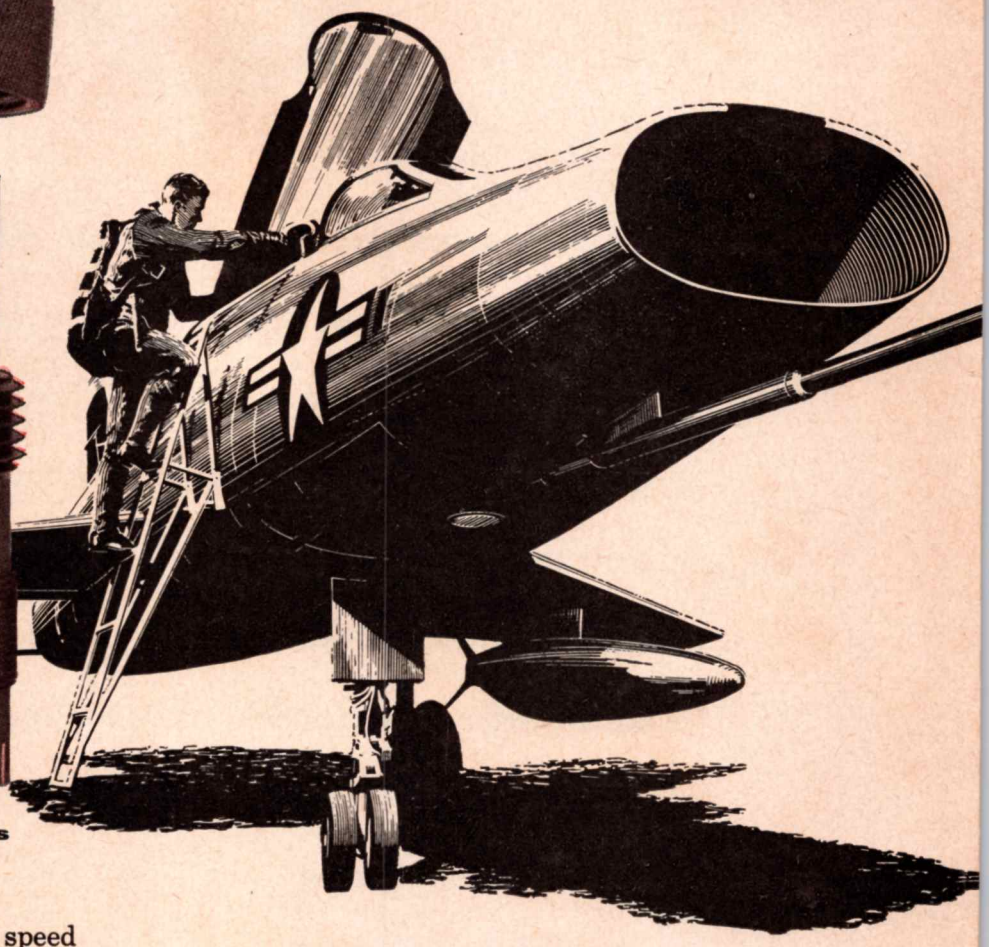
For further information circle Reader Reply No. 24

WIG-O-FLEX® couplings save 46 pounds on North American F-100c



Flexible union for connecting rigid tubes



THE WORLD'S FIRST supersonic speed record holder—the North American F-100C SUPER SABRE—is 46 pounds lighter because WIG-O-FLEX Couplings replaced standard AN connections and cut hose. WIG-O-FLEX Couplings weigh 1/5 as much as the standard AN connections they can replace.

Write for further information.

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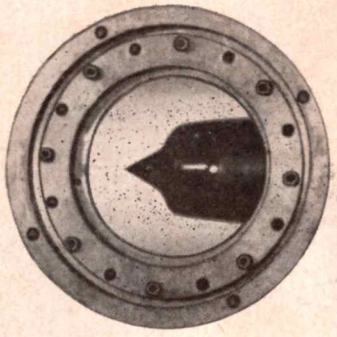

This is a model of an inlet air diffuser for turbojet engines, mounted in a supersonic wind tunnel. To assure maximum performance, the diffuser must position and maintain the proper shock wave pattern at the engine inlet. This is done by an automatic control which positions the diffuser correctly under all flight conditions. Without this Honeywell control, a supersonic aircraft might never reach design speed.

AERONAUTICAL DIVISION, MINNEAPOLIS-HONEYWELL

For further information circle Reader Reply No. 18

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AVIATION ENGINEERING

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PROBLEMS OF AEROPHYSICS IN THE HYPERSONIC REGION 21
John W. Bond, Jr.
Dissociation and ionization of air influence design.

CAPACITOR TYPE FUEL GAGES AND CONTROLS 26
Sanford Solarz
Fuel gage systems meet operational requirements.

RAMJET-TURBOJET POWERPLANTS CAN EXTEND FLIGHT REGIME 30
Joseph Friedman
Range, ceiling and thrust-to-weight ratio increased.

AIRFLOWS STUDIED IN MINIATURE SMOKE-JET WIND TUNNELS 35
High-speed cameras photograph time sequence.

DESIGNING FOR HIGH-SPEED MISSILE COOLING 48
R. H. Hepper
Aerodynamic heating problems combatted.

AERO FEATURE

SYSTEMS ANALYSIS FOR WEAPONS AND MISSILES 40
William F. Wright and Patrick Benson
Insight into procedures from contractor's and military's viewpoints.

DEPARTMENTS

AERO NEWS DIGEST 5

NEW BOOKS 54

CALENDAR 54

NEW EQUIPMENT 56

TRADE LITERATURE 62

ABSTRACTS 64

EDITORIAL 66

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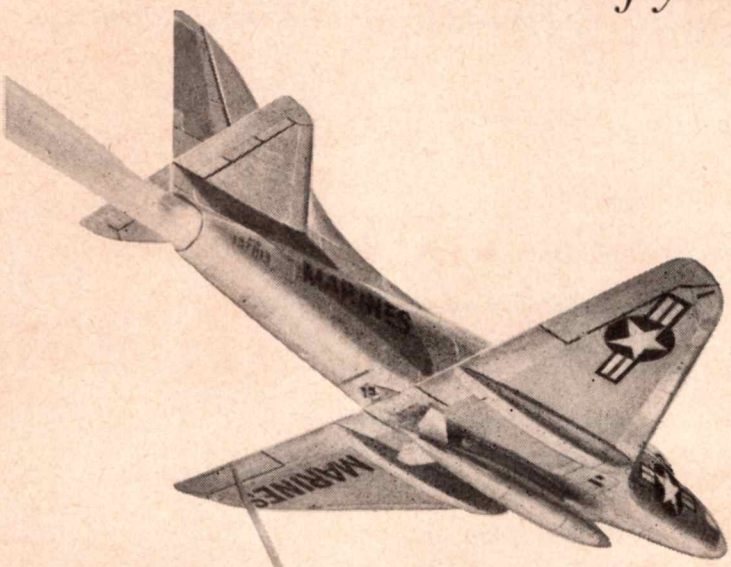
To fly close support for Marine riflemen



A masterpiece of combat teamwork is the co-ordination between Marine planes and ground forces. With a Marine pilot on the firing line directing the aircraft above, strikes can be pinpointed where they're needed.

Scheduled to fly with the Marines on such missions is the Douglas A4D Skyhawk. Designed as an attack bomber, this smallest of all carrier-based aircraft is also well adapted for the lightning in-out tactics of close support. Its payload—including nuclear weapons—carries a crippling punch.

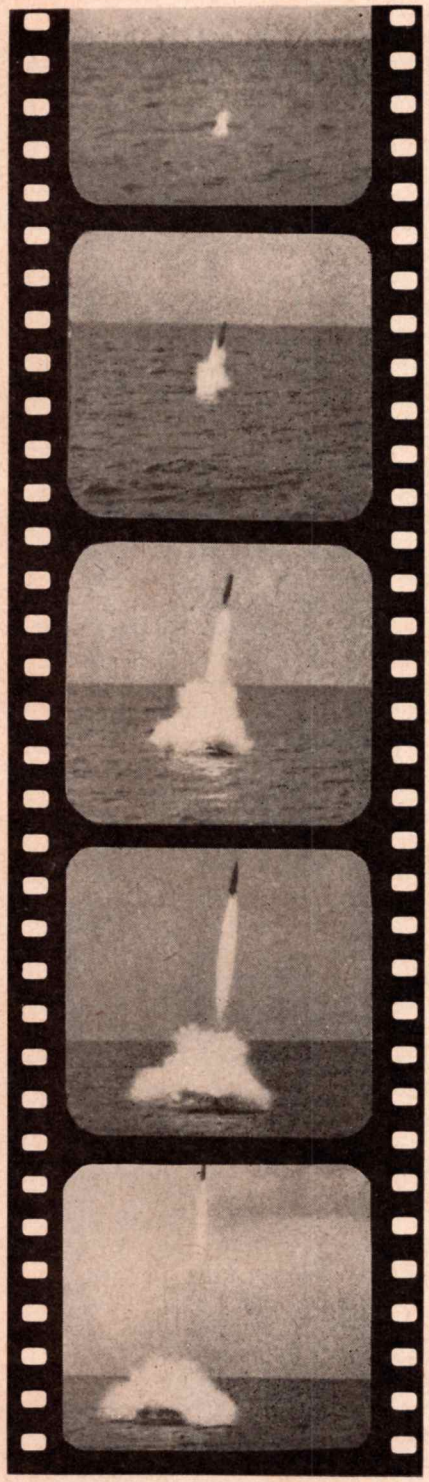
Douglas A4D Skyhawk

The agile Skyhawk is only as effective as the pilots who fly it. Now, for the first time, college seniors or recent graduates may apply directly for Pilot Training through a new program known as Marine Aviation Officer Candidate Course. For information, write: Commandant of the U. S. Marine Corps., Code (DI), Washington 25, D. C.

Depend on *DOUGLAS* **First in Aviation**

aero news digest

Most Fantastic Missiles Yet Under Study by the Navy



Guided missiles that can be launched from submerged submarines against enemy subs, surface ships, aircraft and surface targets are being studied intensively by the U. S. Navy. AERO DIGEST reported last year that the Soviets had developed a missile that could be fired from a submarine at 300 foot depths and hit surface targets up to 140 miles away, but until recently no such missile has been included in the U. S. arsenal.

The Germans developed underwater-to-surface missiles as early as 1944. Although films and technical reports on these missiles have been in the hands of the Defense Department for 11 years, not until today have there been indications that we are doing something about it.

In 1944 the German submarine commander Hans Steinhoff (brother of Dr. Ernst Steinhoff, now at Holloman AFB) took his sub into the Casablanca harbor. Through his periscope he eyed thousands of barrels of gasoline and oil, hundreds of trucks, tanks, guns and other vital materiel. But he could not do anything about it; he would be a sitting duck if he surfaced.

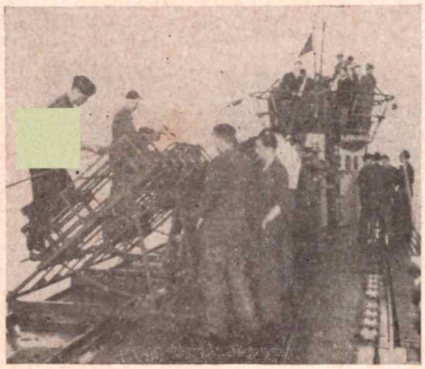
On his way back to Stettin, Steinhoff conceived the idea of using underwater rockets, missiles that could be launched from submerged positions far off the enemy coast and hit surface targets such as the Casablanca harbor. Back in Stettin Commander Steinhoff rushed to Peenemünde for a talk with his brother, who was then in charge of Wernher von Braun's electronics and guidance division.

These three men, under von Braun's guidance, developed a submarine deck-mounted launcher designed to hold four large solid propellant rockets. Each rocket was to be fired at a 45° angle.

Nobody knew whether rockets could work under water, but it was considered worth a try. The submarine went down to 100 feet, the ignition for the first missile was activated, and the rocket popped out of the sea and roared aloft.

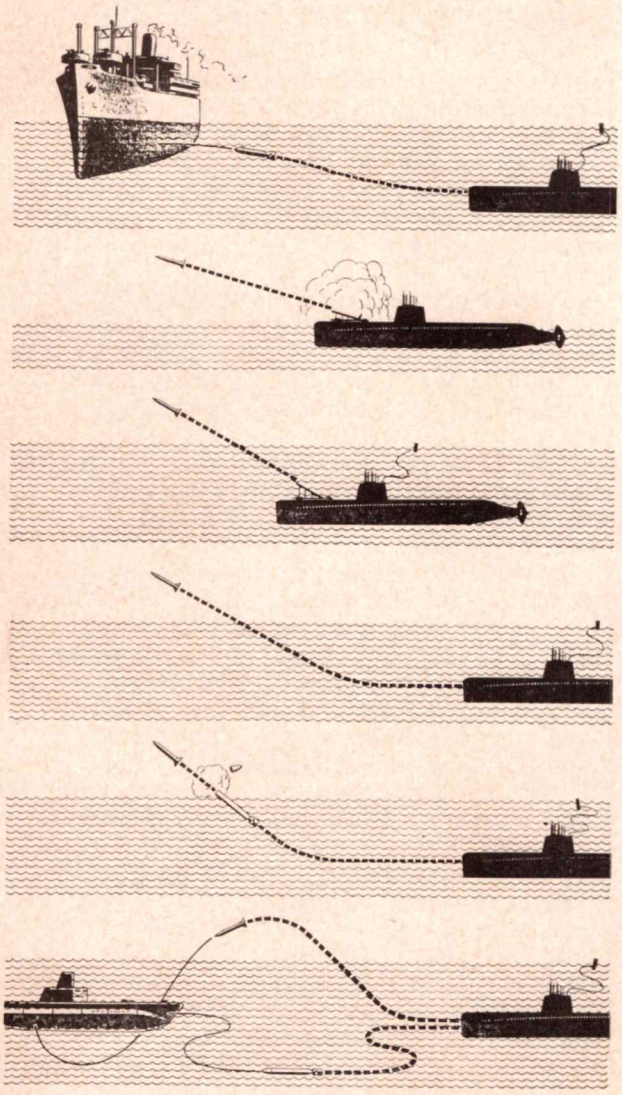
It was found that due to the water back-pressure effect on the missile, it did not burn much propellant on its way up to the surface, with the result that the missile's range was almost unimpaired. As a matter of fact, the distance traveled by the submerged rockets was just as far as that of a surface-launched rocket of the same type. The missiles used were of the 21-cm Borsig type.

In spite of the successful experiments, the Germans did not complete development of the new system, owing to inter-service jealousies. The Navy could not tolerate that the Army develop a weapons system for them. Commander Steinhoff surrendered his sub in Boston harbor at war's end, then shot himself. The Russians, meantime, moved all Nazi underwater missile gear and hardware to the Soviet. The United States got the



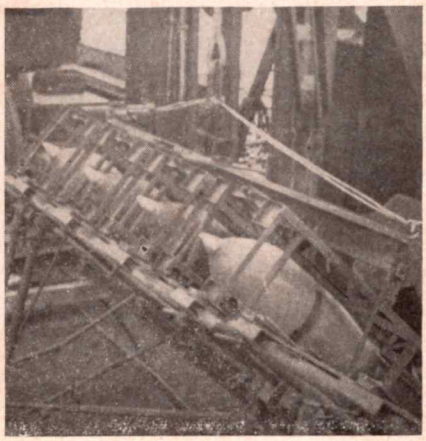
technical reports and the men who developed these fabulous missiles.

Since the German development, additional concepts for underwater missiles have been conceived. Aerojet-General Corporation has been working for the Navy at Key West for some time on underwater rocket propulsion. Generally, three different underwater missiles are recognized as being worked on in both the Soviet and the United States—underwater-to-underwater missiles, highly advanced super torpedoes that can be used against enemy subs as well as surface vessels; underwater-to-surface rockets, based on the German solid rocket developments; and underwater-to-air missiles, an entirely new concept in submarine defense against attacking aircraft.



In the underwater-to-surface category are also included large missiles that can possibly supplement our current ICBM systems. As a matter of fact, it is not unlikely that some of our submarines will be built as ICBM launchers in the future. A nuclear-powered submarine can remain off an enemy coast—submerged—for months. When the time for a retaliatory attack is ripe, the submarine will poke to the surface an electronic positioning scanner. After computation the submarine will go into launching position. Its watertight missile chamber will open up, and in darkness and silence the huge weapon will be sent upward and aloft. In an inferno of flames and steam the thermo-nuclear missile will woosh out of the ocean. By the time it hits the target, the submarine is already miles away on its way home.

Submarine personnel will welcome the fact that they will be in position to fire upon attacking aircraft—before the airplane has had a chance to locate the sub. From 300 feet or more down, where there is practically no wave motion, the electronic radar scanning and positioning device will be sent to the surface. This device is too small to be detected at a distance. When enemy aircraft approach the area, the underwater-to-air missiles will be launched, either through the torpedo tubes, or from launchers similar to the ones developed at Peenemüde. As the missile pops out of the water, the small electronic float will make the missile ride a beam toward the airplane. At a given distance the missile will take over the guidance and home in much the same way as is practiced by missiles of the Terrier and Nike types.



These missiles do not necessarily have to be solid-propellant rockets. Liquid fuel missiles can be mounted inside large torpedoes. Shot out through the conventional tubes the torpedoes will turn upward. As they pop out of the water, the reduced pressure on the nose will trigger a release mechanism, the nose flies off, and the liquid propellant missiles take off without having been in contact with the water at all.

One question remains unanswered: what is the state of the underwater missile art in this country? The fact that the Russians took over the German equipment and continued the research and development of underwater

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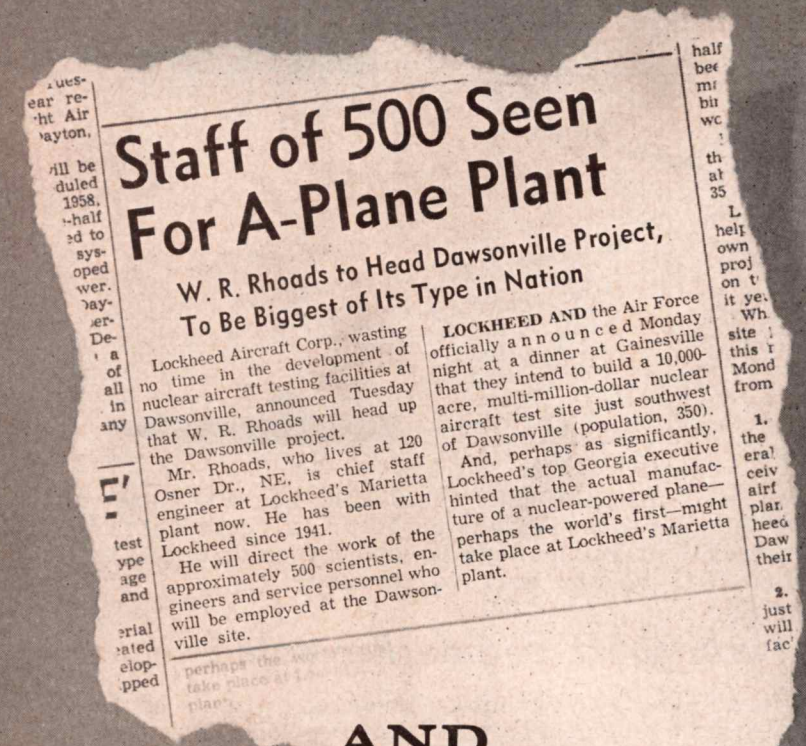
LOCKHEED in GEORGIA MOVES AHEAD AGAIN!



Staff of 500 Seen For A-Plane Plant

W. R. Rhoads to Head Dawsonville Project, To Be Biggest of Its Type in Nation

Lockheed Aircraft Corp., wasting no time in the development of nuclear aircraft testing facilities at Dawsonville, announced Tuesday that W. R. Rhoads will head up the Dawsonville project.

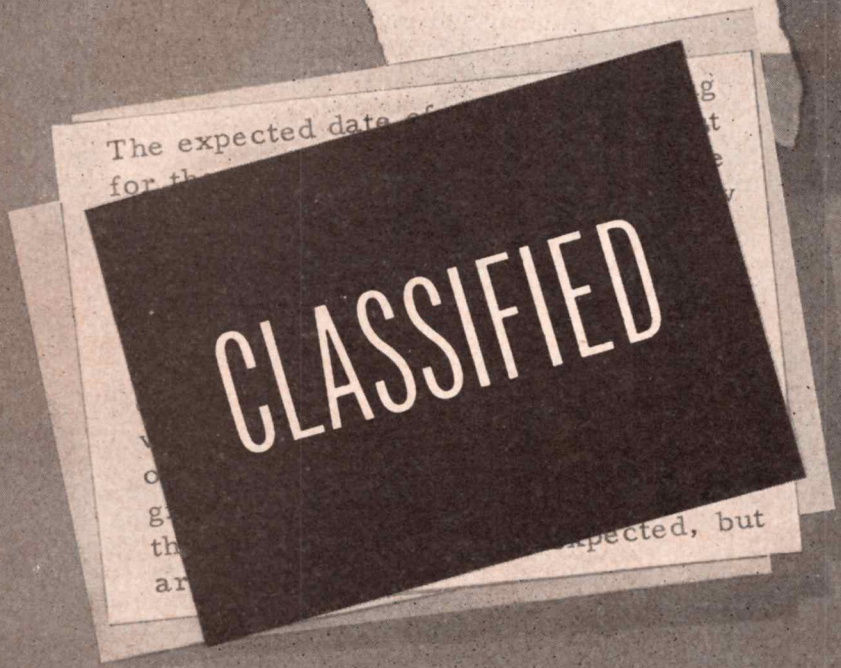
Mr. Rhoads, who lives at 120 Osner Dr., NE, is chief staff engineer at Lockheed's Marietta plant now. He has been with Lockheed since 1941.

He will direct the work of the approximately 500 scientists, engineers and service personnel who will be employed at the Dawsonville site.

LOCKHEED AND the Air Force officially announced Monday night at a dinner at Gainesville that they intend to build a 10,000-acre, multi-million-dollar nuclear aircraft test site just southwest of Dawsonville (population, 350).

And, perhaps as significantly, Lockheed's top Georgia executive hinted that the actual manufacture of a nuclear-powered plane—perhaps the world's first—might take place at Lockheed's Marietta plant.

AND there's more that can't be published—yet



The world's largest integrated aircraft plant, at Marietta, Georgia, — where we build Lockheed C-130 Turbo-Prop Cargo planes and B-47 Jet Bombers—welcomes this new Lockheed program in Georgia.

Here are projects to challenge the very limits of imagination, vision, ability and capabilities of man!

This new atomic development and its effect on the adjacent manufacturing plant and new Engineering facility at Marietta, creates far reaching additional opportunities for Engineers and Scientists in a wide range of categories in both places.

Here is a program that is literally long range in both scope and product.

Qualified Engineers and Scientists interested in becoming associated with this progressive and rapidly expanding organization are invited to inquire for further information or personal interview.

Write to

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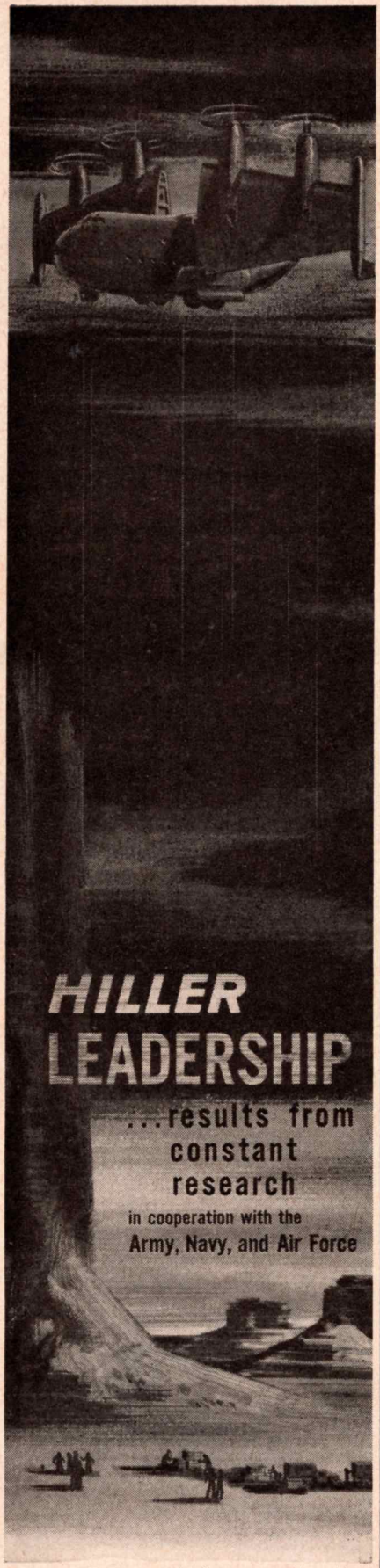

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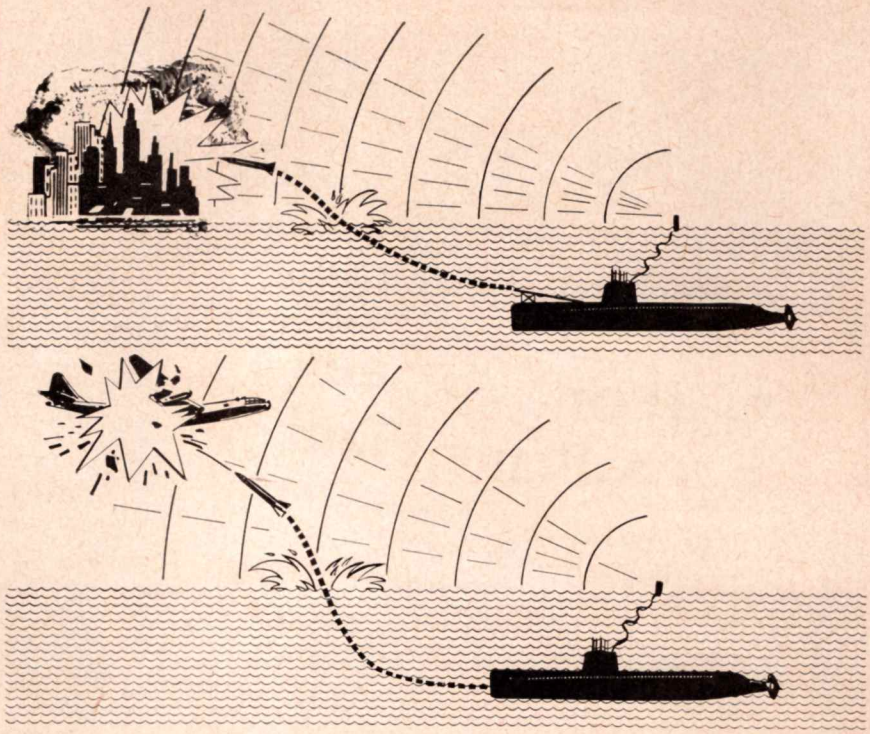

missiles, and the fact that the Soviet has 400 submarines must not be overlooked. Are we 10 or 12 years behind in this field? Or is the Navy in a position to tell the taxpayers that we are well on our way?

T58 Turboshaft Engine Revealed

General Electric recently revealed details of its new T58 turboshaft engine for the Sikorsky S58 Fight Test Vehicle. GE says that their fluid power transmission system offers a wide latitude of rotor speeds for a given power setting and, conversely, offers a wide range of power settings for a given rotor speed. T-58 constant speed control requires a minimum of pilot attention, provides automatic load division between engines in a multi-engine installation and provides a means for resetting the rotor speed when major changes in flight altitude are made. Engine features two-stage axial-flow gas generator turbine and single-stage, axial-flow power turbine mechanically independent of gas generator. The 250-lb T58 (without reduction gear) produces 1050 shp at military rating and has a specific fuel consumption per lb/hr/hp of 0.69 at normal rating. GE claims that the T58 will cost less to operate and will minimize logistic problems because of the engine's ability to use a variety of lower cost aviation and gas turbine fuels.

F-104 Speed Guess

Industry keeps guessing about the speed of the sleek Lockheed F-104 super-fighter. During the first public demonstration the Starfighter went through the sonic barrier and accelerated to a velocity around 1200 mph. Altitude was about 30,000 feet. While some sources say the F-104 airframe has been designed for Mach 3, others indicate that the aircraft actually has flown at speeds in the Mach 2.2 to 2.5 regimes. So far, three aircraft have flown; the X-model has flown for two years. With its significant background in fighter development, Lockheed has again provided the Air Force with a highly advanced fighter. However, possibly the most remarkable achievement in connection with the fighter is its

As flight systems have become more complex, speeds higher, space and weight-saving more valuable, the increasing rate of technical progress in the aircraft industry has created a serious problem:

Keeping its products up to top level of operational effectiveness—and in the air—has become a major responsibility of the prime contractor.

Martin has been working on that problem for many years; and the result is a new kind of service organization and systems method which now provides for the maintenance of all Martin products—from the company's assembly lines to operational flight lines anywhere in the world—at peak effectiveness and with maximum availability.

It is service on a *systems* basis, and already it's setting a new pace in the industry.

MARTIN

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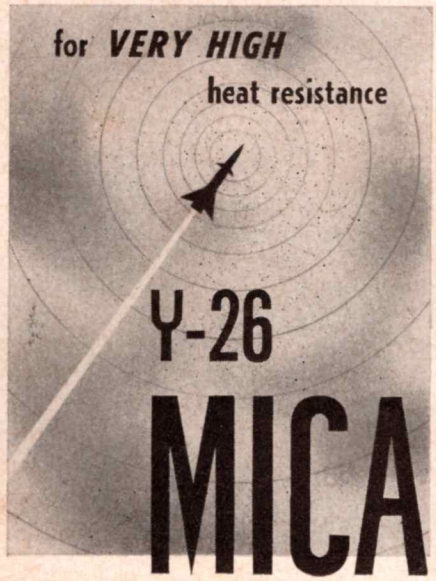

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For further information circle
Reader Reply No. 19

General Electric J-79 engine, truly the finest engine developed in this country to date. Do not be surprised if the Collier's Trophy goes to General Electric next year for its J-79...

ICBM Engines Tested

Aero-General Corporation and North American's Rocketdyne Division each claim that they have the country's largest test facilities for rocket engines. While Rocketdyne's facility, the so-called Propulsion Field Laboratory, at Santa Susana, California, is in full operation, Aerojet's Sacramento site is still under development. Two Aerojet static firing stands are designed for 300,000 pound loads, and a third will take a pull of 1.5-million pounds. At Rocketdyne's facility engines of more than 100,000 pounds thrust have been demonstrated to the press. Much larger engines frequently are being tested. North American's ICBM combustion chambers are said to be of the order of 120,000 to 175,000 pounds thrust. The ICBM engines will have a small "rocket" engine mounted inside the large ones for propellant compression. Propellant delivery rate is so tremendous that no conventional pumps will suffice.

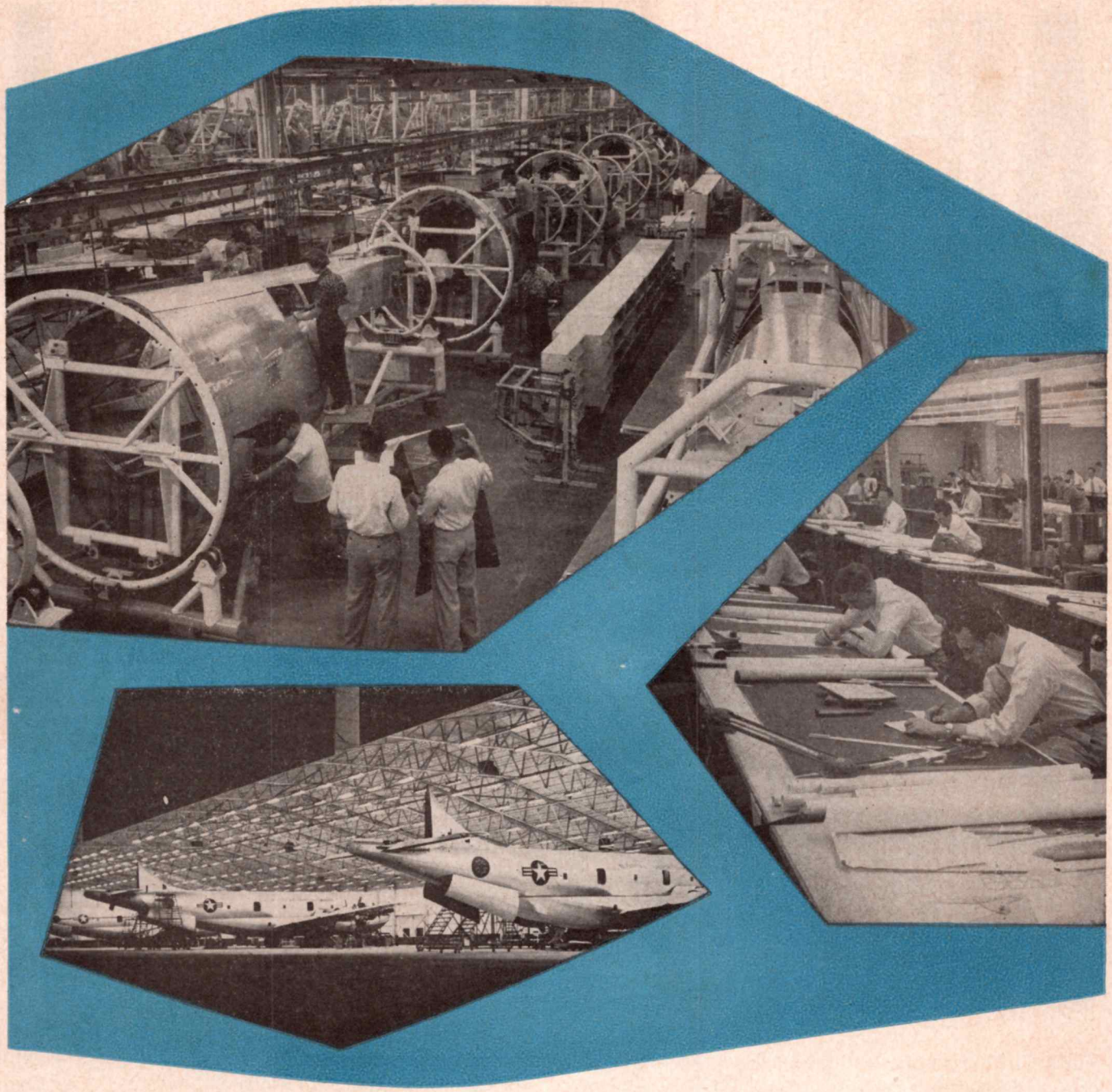
Steel Airplanes

Fifty percent or more of tomorrow's supersonic planes will consist of stainless steel, Republic Steel Corporation predicts. To serve "brand new uses" for the metal, as well as fill expanding needs for existing uses, Republic Steel recently increased by 18 percent its stainless steel manufacturing facilities. Engineers at Republic Steel's Alloy Steel Division emphasize that the appearance and cleanability of stainless will have almost nothing to do with its selection. Many of the stainless components will be deep within jet engines or frame, where they will not be seen.

Names in the News

Goodyear Aircraft Corporation has named T. A. KNOWLES President and VAL L. FOLLOW Vice President in charge of production . . . New president of Actuation Research is RICHARD D. MAYSTEAD . . . TREVOR GARDNER elected Chairman of the Board of Hycon Mfg. Company . . . CLARENCE L. JOHNSON appointed to fill Lockheed Aircraft Corporation's newly-established position of Vice President for research and development and W. R. RHOADS, Chief Staff Engineer of Lockheed's Georgia Division, has been appointed director of the Georgia nuclear aircraft test laboratories to be operated for the U. S. Air Force by Lockheed . . . Walter Kidde Nuclear Laboratories, Inc. elected HENRY K. NORTON Chairman of the Board and WILBER E. KELLEY President . . . Brig. Gen. LANCE CALL, USAF (Ret.) chosen Vice President of Kellett Aircraft Corporation . . . FRED L. DOBLOFF now Chief Engineer of the Helicopter Engineering Division of McDonnell Aircraft Corporation . . . EARL P. STEVENSON new Chairman of the Board and RAYMOND STEVENS now President of Arthur D. Little, Inc. . . . H. K. Porter Company, Inc. appointed CHARLES L. HOLBERT Executive Vice President . . . American Bosch Arma Corporation, American Bosch Division named SIDNEY E. MILLER Vice President and General Manager, and Arma Division appointed ALAN F. THOMPSON Vice President of Manufacturing . . . General Electric elected CRAMER W. LA PIERRE an Executive Vice President and CHARLES R. PRITCHARD a Vice President . . .

ERIK BERGAUST



Temco has the CAPACITY

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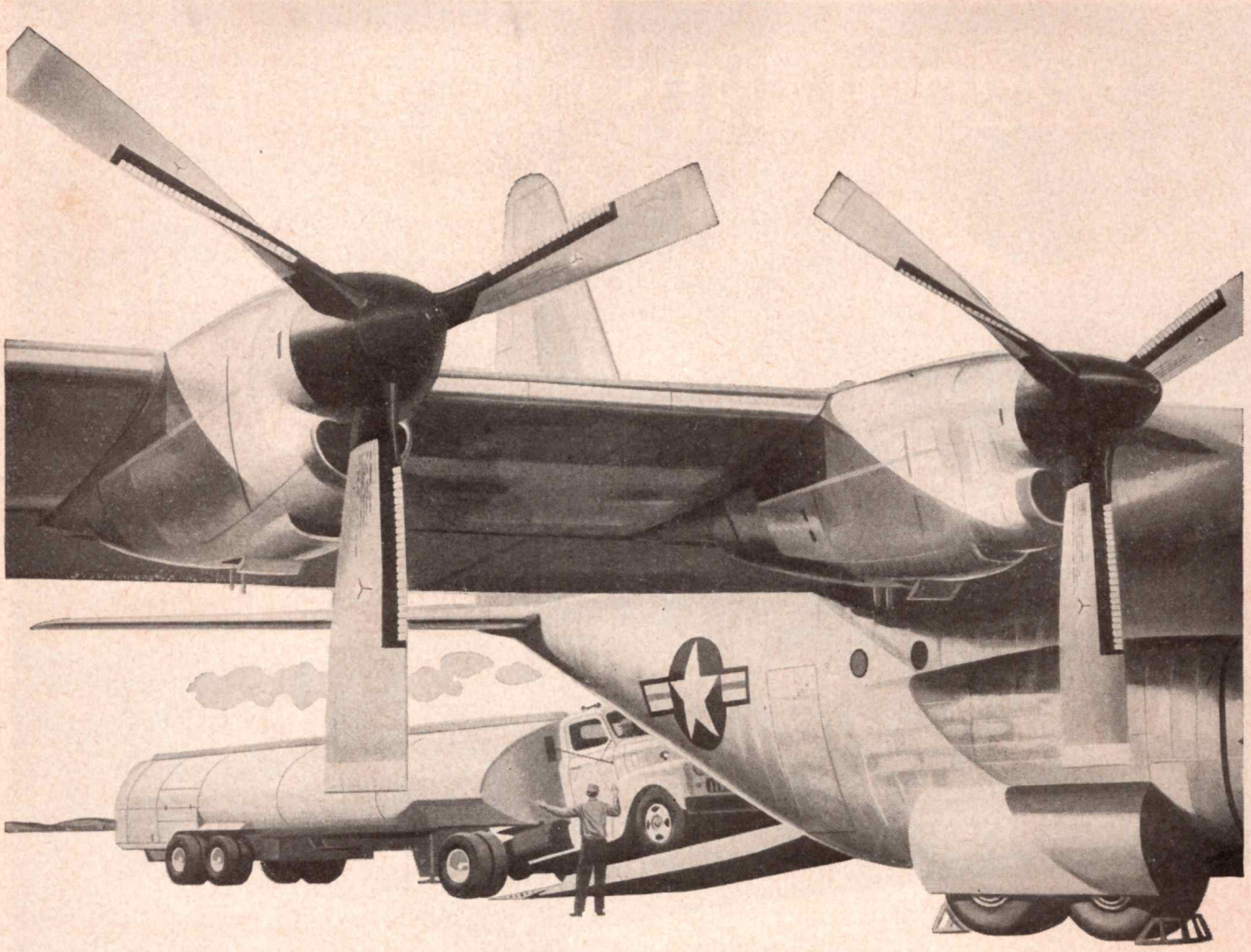

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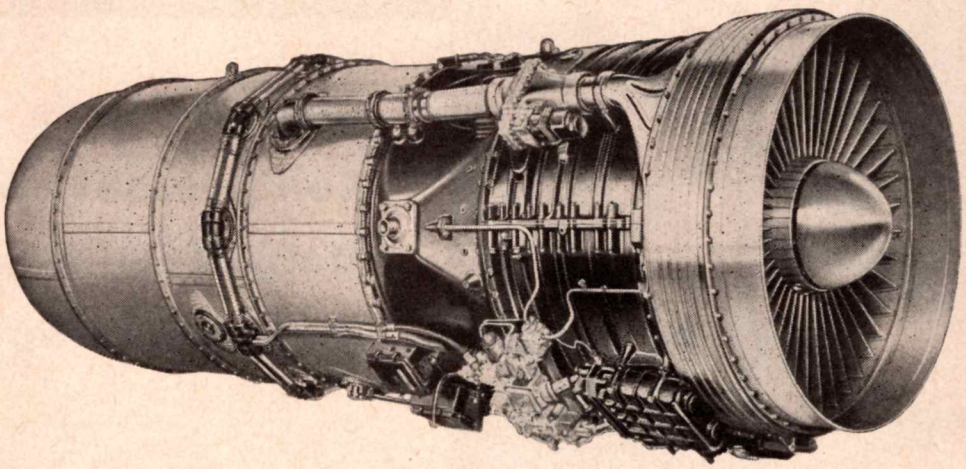

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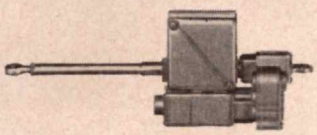

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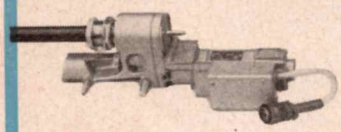

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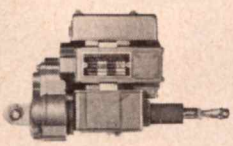

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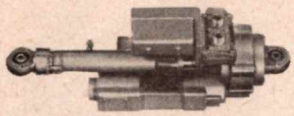

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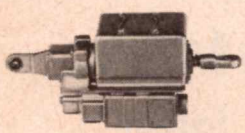

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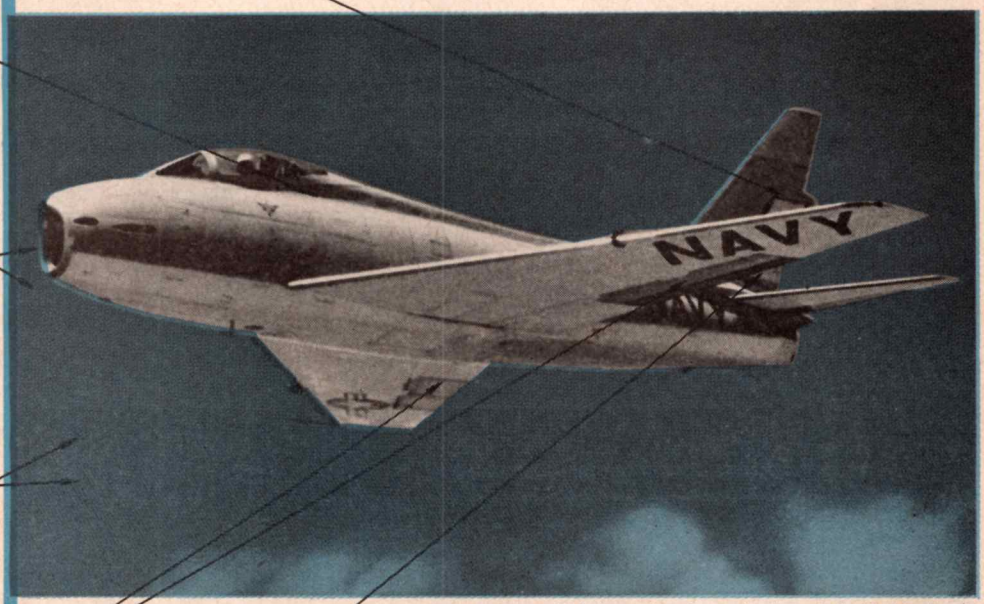

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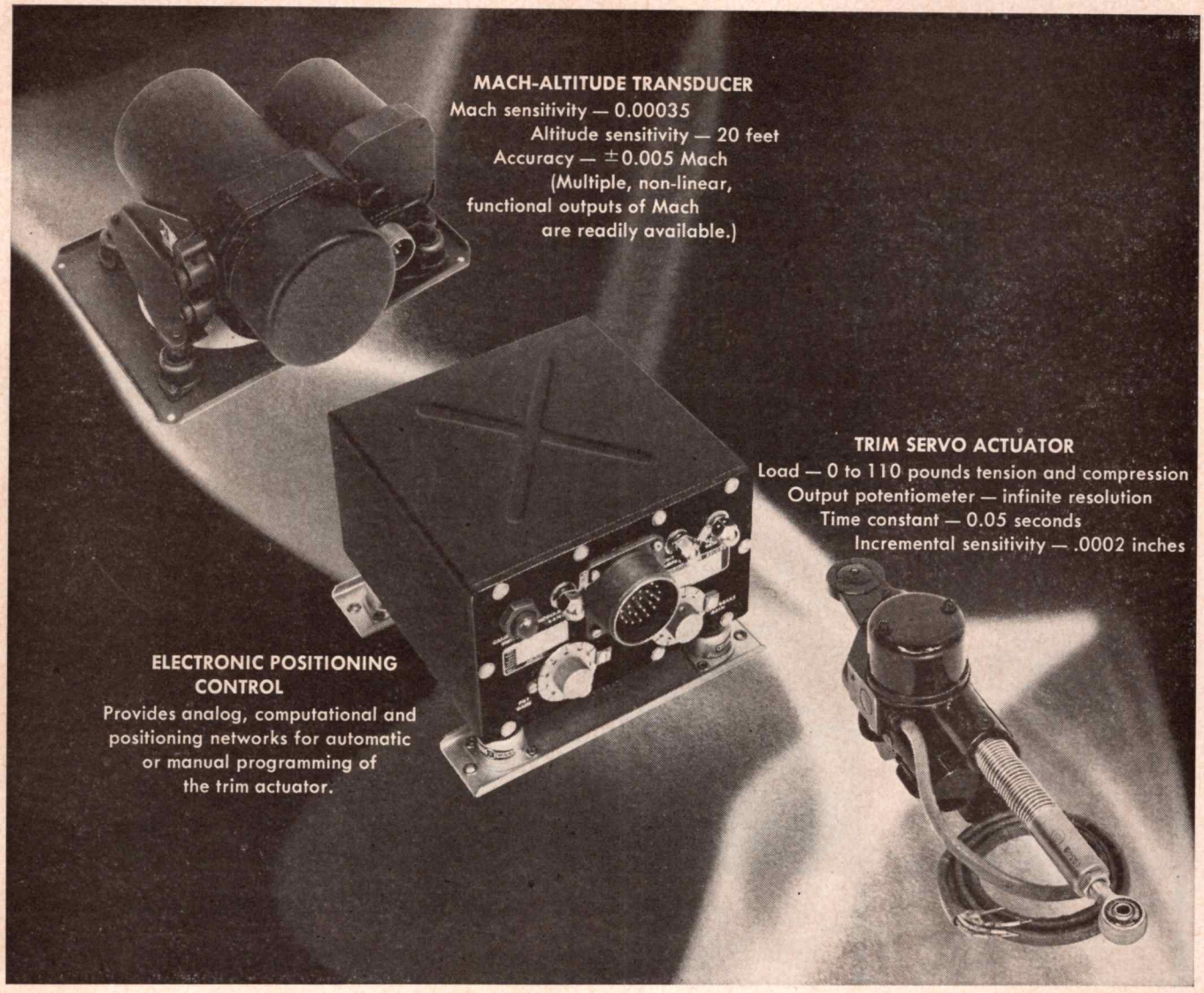
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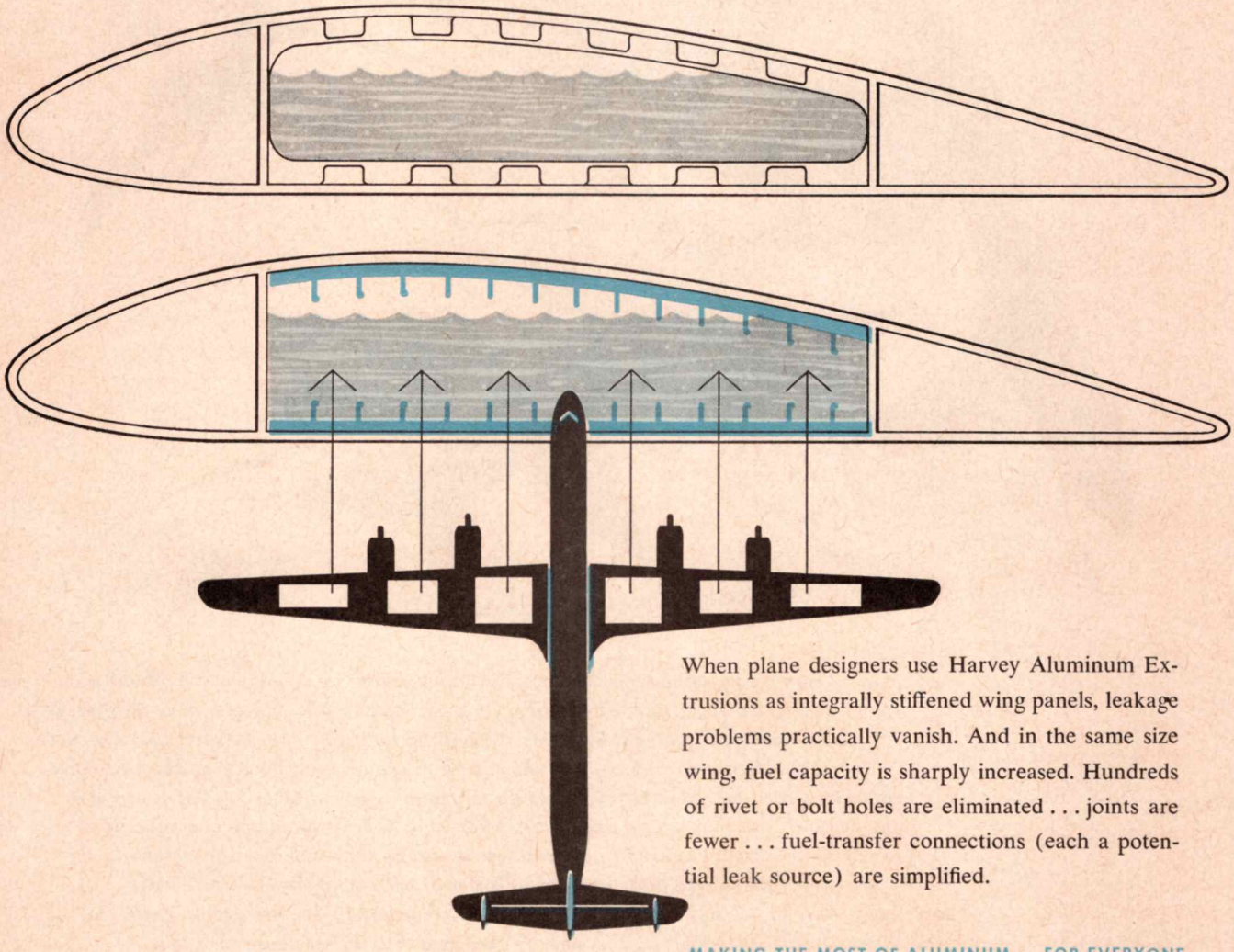

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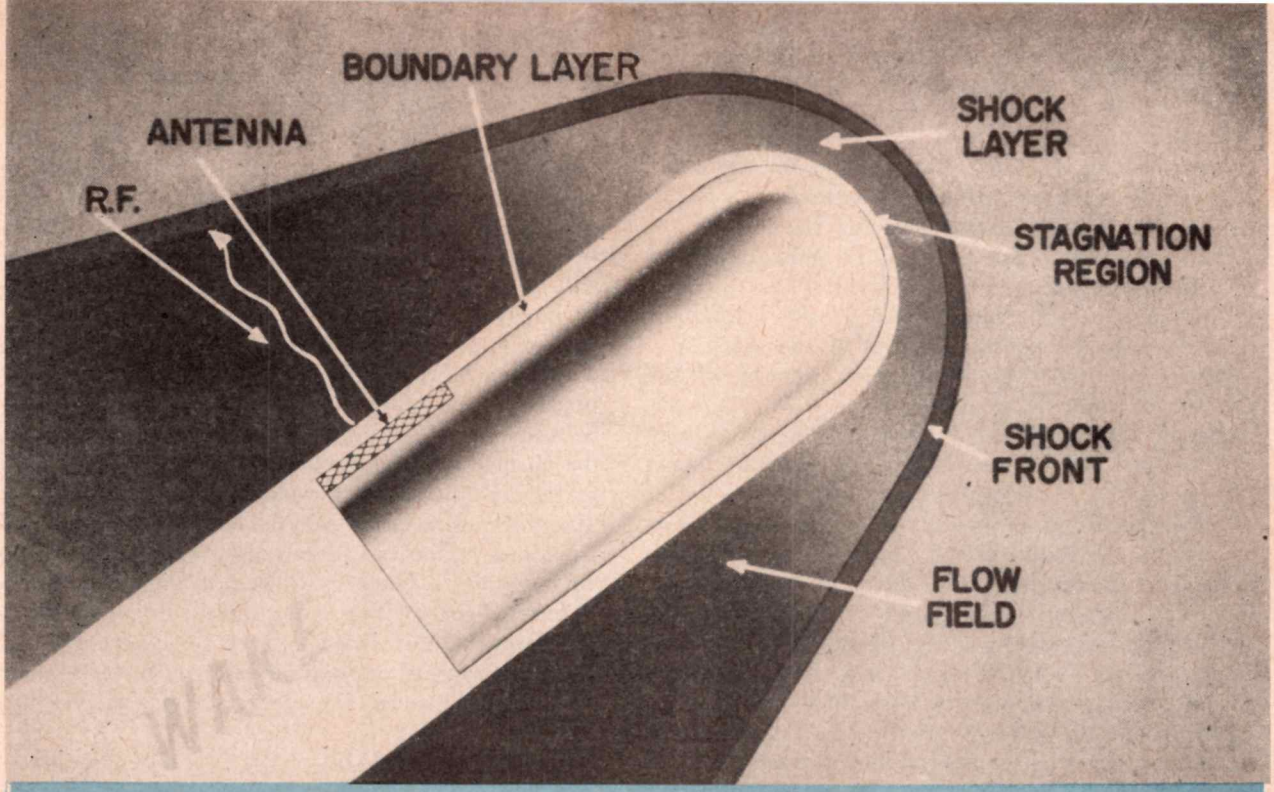


Figure 1—A hemisphere-cylinder traveling through the atmosphere at a high hypersonic speed.

Problems of AEROPHYSICS IN THE HYPERSONIC REGION

JOHN W. BOND, JR.
Aerophysicist, Special Defense Projects Department
General Electric Company, Schenectady, New York

WHEN AN OBJECT TRAVELS through the atmosphere at speeds in excess of about ten times that of sound, the air in the shock wave that precedes the object becomes partially dissociated and ionized. The analysis of the flow and heat transfer problems involves not only a knowledge of aerodynamics but also a knowledge of chemical kinetics and atomic and molecular physics or, in general, aerophysics.

The purpose of the following remarks is to outline briefly a few of the physics problems associated with the flow of air around an object moving at velocities greater than that equivalent to about Mach 10. At these high hypersonic speeds, the heat transferred from the air to the object may be large enough to cause melting, oxidation, sputtering or other deleterious surface effects. If such effects are to be avoided some means of absorbing the heat at a relatively high rate must be found. One possibility is that the object itself have a sufficiently high heat capacity to absorb the heat. In addition, the object may move more slowly at the lower altitudes where the heat transfer rate is large because of the higher atmospheric density.

A detached shock precedes a blunt-nosed object traveling through the atmosphere at hypersonic speeds and the region between the shock front and the surface boundary layer is called the shock layer. It has been pointed out that above speeds of about Mach 10 the air in the shock layer is at such high temperatures that it is partially dissociated and ionized. Hence the physical state or composition of the air may be considerably different than it is at lower Mach numbers. As a result various physical processes such as viscosity, diffusion, thermal conductivity, radiation, dissociative and electronic recombination, electrical conductivity and compressible flow may also be considerably different than at the low Mach numbers.

The flow regions about a hypersonic object are shown in Figure 1. The configuration chosen is that of a hemisphere-cylinder because of its simplicity and since it clearly demonstrates the various flow regions. These regions are, briefly, the shock front, which is the non-equilibrium region between the undisturbed air in front of the shock and the air behind the shock where statistical equilibrium is again realized; the shock layer; the boundary layer, which is a thin layer

At high hypersonic speeds, the dissociation and ionization of air in the immediate vicinity of a vehicle may influence its design. As a result, the development of such vehicles requires a considerable amount of theoretical and experimental research in the fields of atomic and molecular physics.

of slow-moving air next to the surface; and the wake.

It will be useful to define a few terms before beginning a description of the various flow regions:

Shock strength—The ratio of the pressure behind the shock to that in front of the shock.

Compression—The ratio of the density behind the shock to the density in front of the shock.

Shock velocity—The propagation velocity of the shock front.

Sound velocity—Arbitrarily defined as the square root of the derivatives of pressure with respect to density at constant entropy.

Shock Mach number—The ratio of the shock velocity to the sound velocity in front of the shock.

In order to see what sort of temperature and density conditions might be of interest in hypersonic flow problems consider a projectile that has a velocity increasing with altitude from near subsonic below 20,000 feet to perhaps above Mach 20 at 100,000 feet. If the projectile is blunt-nosed as in Figure 1, the conditions immediately behind the normal shock at the front of the projectile may be readily obtained from the hydrodynamic equations of motion, the equation of state of the air and the velocity trajectory. The corresponding values of temperature, pressure and density are shown in Figure 2. It is seen that at about 30,000 feet, the temperature behind the normal shock is about 2000° Kelvin increasing to about 7500° at 100,000 feet. The shock strength, or pressure ratio, is about 650 at 100,000 feet, which means that the pressure behind the normal shock is 650 times as great as the ambient air pressure in front of the shock. The shock strength is less than 100 at 30,000 feet. The compression, or density ratio, is less than 6 at 30,000 feet increasing to 13 at 100,000 feet, that is, at 100,000 feet the density behind the normal shock is 13 times its value in front of the shock.

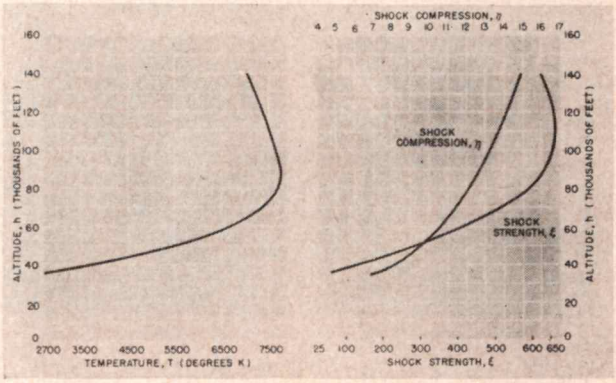


Figure 2—Stagnation values of the temperature, compression and shock strength for the trajectory.

● ● State of Air in Shock Region

It has been pointed out that because of the high temperature behind the normal shock the air will be partially dissociated. In Figure 3 the chemical composition of the air behind the normal shock is shown as a function of altitude for the conditions specified in Figure 2. At 100,000 feet the composition is 50 percent atomic nitrogen, 24 percent molecular nitrogen and 26 percent atomic oxygen. Thus it is apparent that the mixture is entirely different from air at low temperatures. Consequently, many of the physical properties to be discussed are different for air at high temperatures than they are for air at low temperatures.

At lower altitudes the composition in the shock layer changes considerably. The increase in the amount of nitric oxide should be particularly noted because of its influence on such physical processes as ionization, reaction rates and radiation. Below about 30,000 feet the composition of the air is normal.

Since the physical state of the air in the shock layer changes for shock velocities greater than about Mach 10, it becomes important to know the equation of state of the air in the shock layer. The equation of state is a relation between pressure, density and temperature derived on the assumption that the gas is in a state of thermodynamic equilibrium. It has been noted that the equation of state coupled with the hydrodynamic equations of motion and the velocity trajectory specifies the values of the thermodynamic variables and the composition in the shock layer.

In many treatments of shock phenomena the shock front may be assumed to be a mathematical discontinuity. However, Figure 1 shows the shock front to be a thick line varying in width from a minimum for the normal shock, that is, on the axis, to a maximum in the oblique shock towards the rear of the flow. This thickness follows from the definition of the shock front as a region in which translational energy of the air molecules is being transferred to the various types of internal energy. For strong shocks of the sort under consideration, there are many types of internal energy and the energy transfer processes require correspondingly different times. The energy transfer process continues until statistical equilibrium between all the internal energy levels is reached.

The shock front thickness further depends on the density, being greater for the lower densities, hence increasing with altitude; and it depends on the shock strength, being greater for the lower shock strengths. This latter variation is shown in Figure 1 where the shock front thickness is seen to increase as the obliquity increases—the shock strength, of course, decreases with increasing obliquity.

Conditions such as pressure and temperature in the shock layer or inviscid flow field are of vital importance for aerodynamic considerations such as stability. They are further important in the determination of the boundary layer heat transfer rates, shock layer radiation and radio transmission through the ionized shock layer. The inviscid flow field is shown in Figure 1 as the region between the shock front and the boundary layer. Its thickness is assumed to be large compared to that of the shock front or of the boundary layer. Furthermore, at least at low altitudes, it is probably a region of thermodynamic equilibrium. At lower densities longer times are required for two air atoms to recombine into an air molecule; thus the inviscid

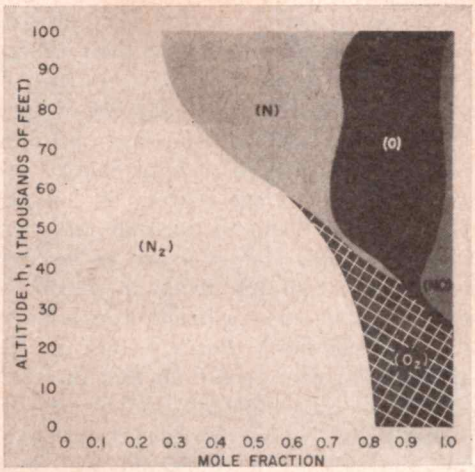


Figure 3—Composition of the air in the stagnation region of the shock layer for the trajectory

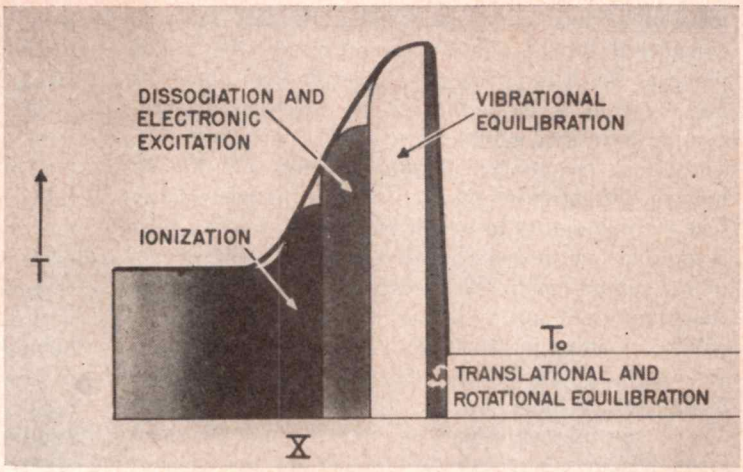


Figure 4—Schematic representation of a strong shock front in air.

flow field may be a region of non-equilibrium conditions at the higher altitudes.

The term inviscid flow field implies that such dissipative processes as viscosity, diffusion and thermal conductivity have negligible effect on the flow properties. This, in turn, implies that the variation of pressure, temperature and density in the transverse direction is small. (In case these effects are not small an inviscid flow field does not exist.)

• • Flow Field and Transport Properties

The inviscid flow field can be divided into three regions for computational purposes. The first is the stagnation region in the front where the flow velocity is negligibly small. The second is the subsonic region where the flow velocity relative to the surface is subsonic. In the vicinity of 40° to 45° away from the axis the flow becomes sonic and, hence, the third region is the supersonic field downstream from the sonic surface. The computation of these various flow regions is difficult for the following reasons: (1) the equations of motion for an axially symmetric flow field are quite complicated, (2) the composition of the gas is variable, and (3) the sonic surface depends on the velocity of sound which is not well known for partially dissociated air. It should be pointed out that it has only been with the recent development of very large computing machines that detailed integration of the axially symmetric flow field could be considered. It is still, however, questionable whether the latest machines are capable of handling the problem.

As was shown in Figure 3, the composition of the air in the shock layer is quite different for high shock velocities than for low shock velocities. In addition, however, many of the chemical species have an abundance of quantum states in various excited electronic energy levels. Consequently, the transport properties, viscosity, diffusion and particularly thermal conductivity may be entirely unlike the values for ordinary air. The assumption that the effects of the transport properties on the inviscid flow field are small depends on knowing what the transport processes are in the temperature range 1000° to about 10,000° Kelvin. Unfortunately, they are not well known in this temperature range and are extremely difficult to obtain either theoretically or experimentally. Of particular importance is the influence of the transport properties on the structure of the boundary layer. In this case some second order effects such as thermal diffusion. which is particle diffusion because of temperature gradient rather than density gradient, may possibly be important.

Since the gas in the shock layer is partially ionized the transport of electric charge, or the electrical conductivity, is affected. This enters into the telemetry problem which will be discussed further on.

Details of the processes of dissociation, ionization and recombination are of importance in determining whether or not the gas is in a state of thermodynamic equilibrium. This results because these processes do not occur instantaneously but rather require varying lengths of time; hence they are referred to as relaxation processes.

The boundary layer shown in Figure 1 is extremely thin near the front of the object becoming thicker towards the rear. It is a region in which the flow velocity of the gas changes from zero in the gas immediately adjacent to the surface to the value in the shock layer, or free stream, at the outer edge.

If the air in the shock layer radiated as a black body, the amount of heat transferred to the surface of the object by radiation would be extremely serious. The air in the shock layer will radiate because of the presence of electrons, ions, atoms and molecules in various excited energy states. Since there are many radiative processes for such a mixture a detailed knowledge of the composition of the shock layer is important if these various processes are to be evaluated and the radiative heat transfer computed. A knowledge of the radiation characteristics may also be useful in observing details of the flow field as well as in observing the trajectory of an object as it penetrates the atmosphere.

The wake shown in Figure 1 is pictured as being blank largely because not much is known about its structure. Hence, it will not be discussed.

In addition to the above problems which all belong in the aerophysics area, there are complicated prob-

lems in surface effects and materials that must be considered for objects traveling through the atmosphere at Mach numbers much greater than about 10. For example, some of the surface effects are melting and evaporation, sublimation, oxidation, absorption, sputtering, secondary electron emission and ion reflection. Of extreme importance is the process of surface recombination in which two atoms unite to form a molecule at the surface and transfer their energy of recombination to the surface in the form of heat. Also important are collisions of the second kind in which an atom or molecule in an excited quantum state transfers its energy of excitation to the surface in the form of heat.

The transmission of radio signals through the shock layer becomes increasingly difficult as the velocity of the object increases. This condition results because of the corresponding increase in ionization and, hence, in the electron density in the shock layer. If the transmission of radio signals is a requirement, then the degree of ionization in the shock layer could well serve as an upper limit to the speed of the object through the atmosphere. The determination of the power required to transmit a radio signal through the shock layer depends upon the signal frequency and on the distribution of electrons in the shock layer. The electron distribution depends, in turn, on the structure of the flow field and on the interactions between the electrons and the various particles in the flow field. Both the flow field structure and the electron interaction problem are difficult and neither has been solved satisfactorily.

• • Shock Front and Boundary Layer

The shock front has previously been defined as a non-equilibrium region in which energy is being transferred from the translational degrees of freedom of the gas molecules to various internal degrees of freedom such as rotation, vibration, dissociation, electronic excitation and ionization. The structure of the shock front depends upon the rate at which energy is transferred, which in turn depends upon the amount of energy required to excite a particular energy level.

In discussing the shock front structure for air, we find it convenient to use the electron-volt (ev) as an energy unit. The relationship between the electron-volt and various other energy units is given as 1 BTU = 252 calories = 1.05×10^{10} ergs = 6.6×10^{21} electron-volts. Also, one electron-volt is equivalent to 11,604° Kelvin; hence the shock layer temperature near the stagnation point is in the range of 0.4 to 0.8 ev for the particular trajectory shown in Figure 2. The atmospheric temperature in front of the shock is near 0.03 ev.

An air molecule is diatomic, hence may be thought of as resembling a dumbbell. Such a molecule may rotate or vibrate with respect to its center of gravity and the rotational and vibrational energies are quantized. The respective energy levels are spaced at roughly 0.001 and 0.1 electron-volts. An additional degree of freedom is that of electronic excitation. For the oxygen molecule, the lowest level is at about one electron volt. Dissociation and ionization may also be thought of as degrees of freedom and their energy levels are at 5 and 13 electron-volts.

The time required to the various degrees of freedom increases as the value of the corresponding energy level increases. Hence, in a strong shock front the translational and rotational degrees of freedom are excited first, the time required to equilibrate their energies being very small. This is shown as the first region behind the front of the shock in Figure 4, where temperature is plotted as a function of distance behind the front of the shock. For a feeling for the order of magnitude involved, one finds that the peak temperature might be about 20,000° Kelvin and the equilibrium temperature behind the shock front about 7000° Kelvin. The shock front thickness may be a fraction of a millimeter and the shock Mach number about 20.

Vibrational energy levels are considerably higher than rotational energy levels and the time required to equilibrate the vibrational energy levels is correspondingly longer. As energy is transferred from the translational levels to the vibrational levels the temperature, which is a measure of the translational energy, drops. The temperature drops still further as energy is transferred into the remaining degrees of freedom until, finally, complete equilibrium among all the degrees of freedom is reached.

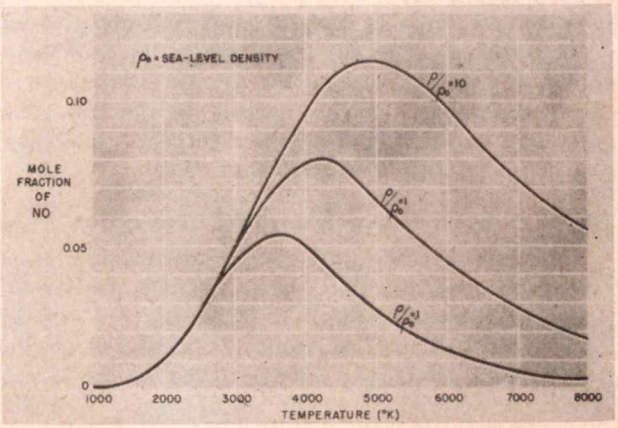


Figure 5—Concentration of NO as a function of density and temperature.

The computation of shock front thickness for air is made especially difficult by the formation of nitric oxide in the shock front. For example, there is no nitric oxide in front of the shock, whereas the equilibrium concentration behind the shock may be as high as 10 percent, depending on the velocity and altitude. The problem is further complicated because the equilibrium concentration of NO has a maximum at about 5000° Kelvin and decreases rapidly for either higher or lower temperatures. This variation is shown in Figure 5 where the concentration of NO is plotted as a function of temperature for several different values of density.

If the density of the air about the object is sufficiently high the flow velocity of the gas particles immediately adjacent to the surface will be zero. If we

assume the flow of gas in the boundary layer to be laminar, and then proceed away from the surface in a normal direction, the flow velocity increases monotonically until it reaches the free-stream value in the shock layer. The distance required to reach this value is the boundary layer thickness. A schematic diagram of the velocity profile of a laminar subsonic boundary layer is shown in Figure 6. This may be thought of as an enlarged section of the boundary layer near the front of the object shown in Figure 1.

If the temperature of the surface remains below its melting point, then the gas temperature through the boundary layer decreases from the free stream or shock layer value to that of the surface. This fact is shown schematically in Figure 7, which corresponds to a case where the free stream temperature might be 7000° to 8000° Kelvin and the surface temperature much lower. Since the temperature decreases and the pressure through the boundary layer does not vary much the density must increase in the direction of the surface.

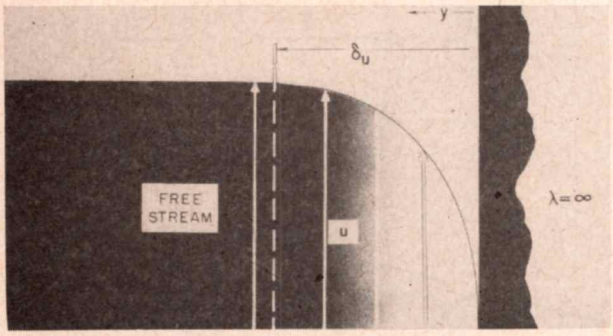


Figure 6 — Velocity profile of a laminar boundary layer.

The boundary layer thickness is generally quite small and, hence, the corresponding temperature and density gradients quite large. For partially dissociated air this may result in a diffusion velocity in the direction of the surface and of such magnitude that a considerable number of dissociated particles actually reach the surface. The heat transferred to the surface depends upon the temperature gradient at the surface, the number and types of particles that reach the surface, and the various transport coefficients. Therefore, a detailed knowledge of the structure of the boundary layer is necessary for an accurate determination of heat transfer rates. For example, if recombination of atoms to form molecules occurs through the boundary layer the potential energy of recombination is converted to kinetic energy or heat. This increases the temperature of the gas and the resulting temperature distribution might look something like the upper curve in Figure 7, while the lower curve would correspond to no recombination.

Under certain conditions the laminar boundary layer may become turbulent. If this happens, the hot gas in the shock layer may be brought much closer to the surface than for the laminar boundary layer case. This, of course, results in a large increase in the heat transfer rate.

For a gas that is not dissociated, the surface is heated by simple transfer of kinetic energy of the gas particles to the surface. However, the gas particles in a partially dissociated gas contain, in addition to kinetic energy, various levels of potential energy such as those due to electronic excitation, dissociation, ionization and vibration. Thus, the surface may be heated both by the direct transfer of kinetic energy and by the transfer of potential energy that is converted to kinetic energy (or heat) by secondary collisions and three-body collisions at the surface.

In discussing the various problems not much has been said about their solution. Until the development of the shock tube, the temperature range of interest, namely between perhaps 2000° and 10,000° Kelvin, was not easily accessible in the laboratory; hence experimental values for the quantities needed are lacking. Similarly, theoretical values for many of the desired quantities are unavailable largely because of computational difficulties; although very recently, using large digital electronic computing machines, work has been started on some of the basic properties such as wave functions and transition probabilities. Additional work is expected on very low energy elastic and inelastic scattering cross-sections as well as threshold cross-sections for various reactions.

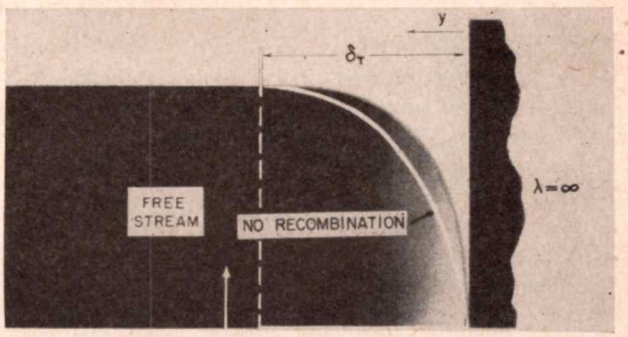


Figure 7—Temperature profile of a laminar boundary layer.

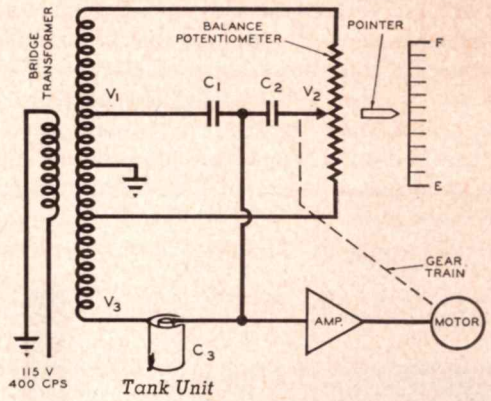
● ● Conclusions

In summarizing the above remarks, we should emphasize that the discussion has been limited to a description of the aerophysics problems associated with the interaction between an object moving through the atmosphere at hypersonic velocity with this environment. In particular, it has been assumed that the surface of the objects absorbs heat at a sufficiently high rate so that it does not melt or erode. And finally, it has been assumed that all the heat absorbed is by the object or by the air itself, and not by foreign substances such as impurities. Within these limitations it has been shown how the following subjects are related in the analysis of the flowing of air about a hypersonic object or vehicle: the equation of space of air at high temperature, the structure of the detached shock front, the inviscid flow field, dissipative and relaxation processes, laminar and turbulent boundary layer, gaseous radiation, the wake, surface effects, materials property and radio transmission. END

Capacitor Type FUEL

In choosing fuel gage systems, aircraft designers are tying their requirements into modern aircraft operations. Systems can now allow for disposable fuel tanks, fuel programming to maintain aircraft stability, and indicators to show tank-full during in-flight refueling.

SANFORD SOLARZ
Supervisor of Technical Data
The Liquidometer Corporation
Long Island City, New York

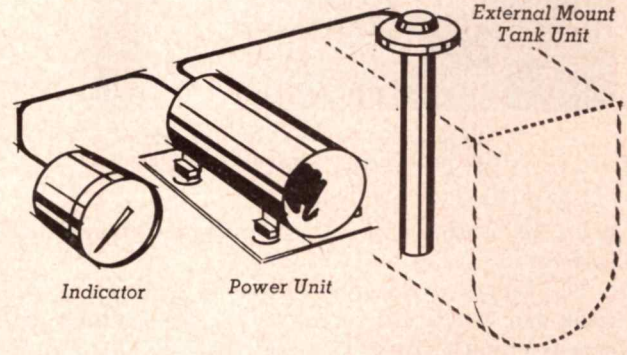


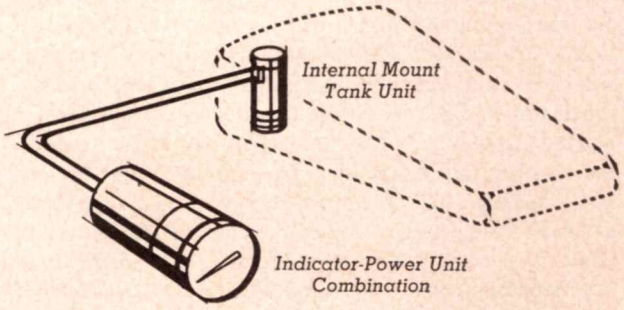
PRESENT DAY FUEL QUANTITY SYSTEMS must do far more than just measure the contents of a tank. Increased aircraft fuel loads and the trend toward automatic flight require gaging systems capable of both measurement and control functions. And, while offering these additional services, they must also be smaller, lighter and more resistant to the ever widening environmental conditions imposed by each succeeding generation of high performance aircraft.

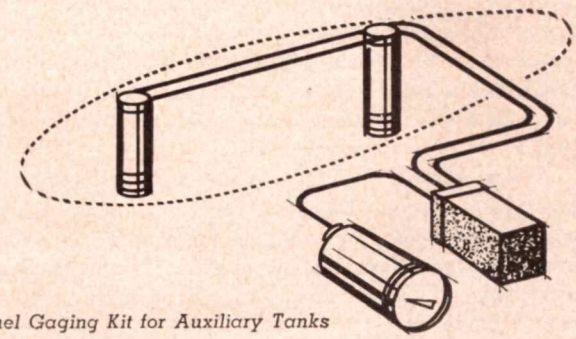
Every new aircraft design presents a new challenge to the fuel gage engineer. For example, repeater indicators may be needed to permit readings at more than one point in the aircraft. Where drop tanks are used, the gage must allow for the removal of their contents from the total indication at the moment they are dropped. Still another problem exists where an operational aircraft must be retrofitted to carry extra fuel in external tanks and these tanks must be gaged without redesign of the existing measuring system.

Where relatively large amounts of fuel must be carried in parts of the aircraft distant from its center of gravity, some method of programming the fuel must be provided to maintain trim. On larger aircraft there may be a need for individual indicators for each tank and also a separate display of total fuel.

The heart of each of the aforementioned systems is one or more self-balancing capacitance bridge networks. Fundamentally, each system consists of a tubular capacitor located in the tank, a capacitance measuring circuit and an indicator which reads directly in fuel quantity. The tank unit consists essentially of two rigidly mounted concentric tubes which form the two electrodes of a capacitor and extends the depth of the tank. Tank unit capacitance varies with fuel level and fuel dielectric constant. Fuel dielectric constant is loosely related to its density and therefore tank unit capacitance related to the weight of the fuel remaining. This capacitance is measured by the bridge network and displayed on the indicator as pounds of fuel remaining.







Fuel Gaging Kit for Auxiliary Tanks

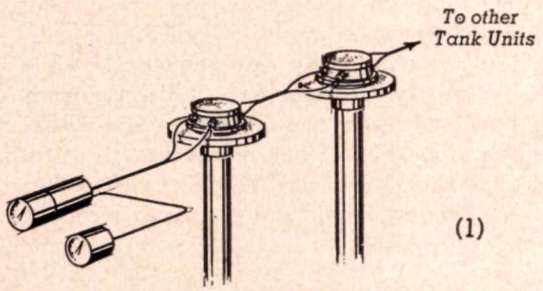
GAGES AND CONTROLS

In the simplified schematic of a basic (or uncompensated) gaging system, tank unit C_3 forms one leg of the bridge network. With the tank filled with fuel the pointer and the potentiometer will be at the upper end of their travel and the bridge will be in a balanced state with $C_3 V_3 = C_1 V_1 + C_2 V_2$. As the liquid level falls, the capacitance of C_3 will decrease, thus unbalancing the bridge and producing a bridge output signal. To rebalance the bridge, in theory, it is necessary to decrease the side of the equation opposite $C_3 V_3$. This is done by repositioning the potentiometer wiper so as to decrease V_2. To reposition the wiper, the bridge output is amplified so that it is sufficiently strong to operate the motor. The motor, through the gear train, drives the wiper and the indicator pointer. When the bridge is rebalanced the pointer will come to rest at a new place on the dial corresponding to the new liquid quantity.

The compensated capacitor type fuel quantity gage is similar to the uncompensated system just described except that it makes use of an additional sensing element which serves to correct for changes in dielectric constant with respect to fuel density. Known as the reference condenser, it is mounted close to the bottom of the last tank to empty. The reference condenser can be provided as a separate unit or as an integral part of a tank unit.

A third method of measuring fuel quantity is the true weight gage. This system considers dielectric constant and density as two independent variables. It measures volume by means of a tank unit and a reference condenser and density by means of a density sensitive rheostat known as a Liquidensitometer. Because it responds to volume and density *only*, it indicates the true weight of the fuel being measured whereas this can be only approximated by uncompensated and compensated gages.

Shown below and on the following pages are a few of the many applications of capacitor type fuel gaging systems. None are theoretical but instead represent installations proposed for, specified for, or presently installed on aircraft.



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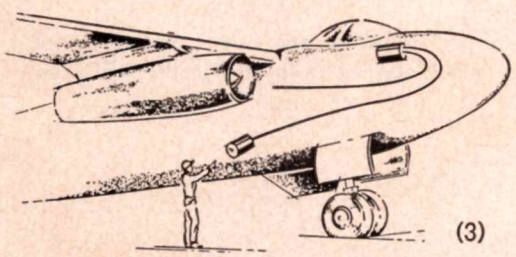

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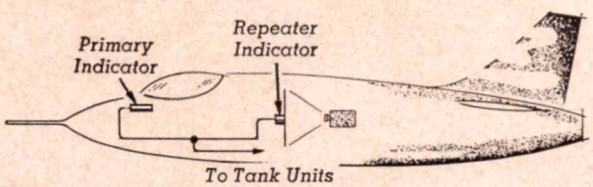

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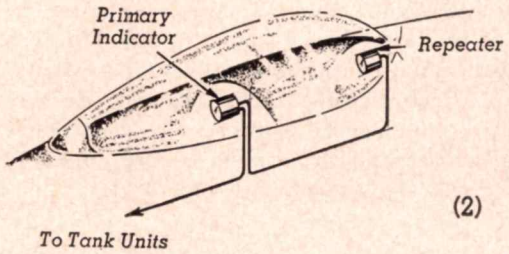
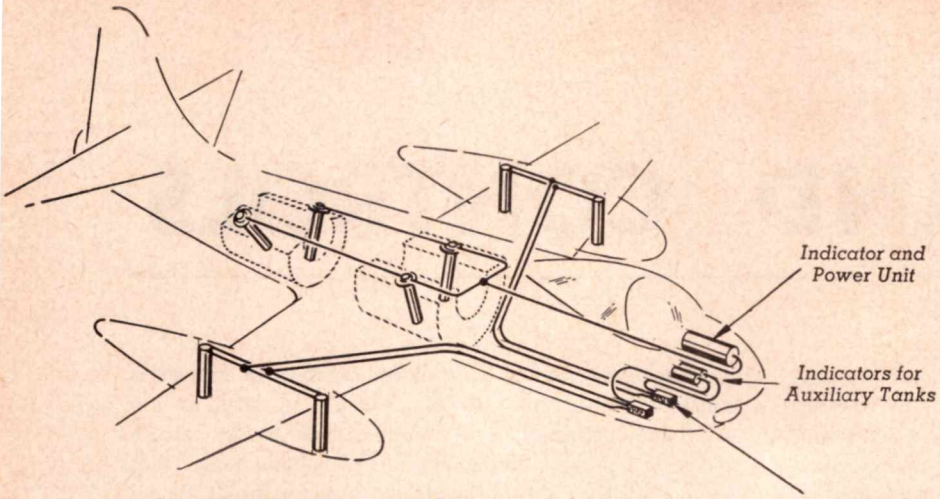
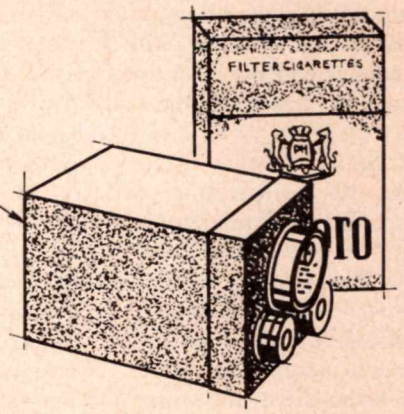


(2)

• • Repeater Indicators

A duplicate fuel quantity indication may be obtained by the use of a second indicator known as a repeater. The second indicator may be in the form of a dc ratiometer or a self-balancing motor driven unit similar to the basic indicator and power unit. A basic repeater system is shown by illustration (1) and consists of whatever number of tank units may be needed to sense the fuel in all the tanks, a power unit and indicator and the repeater. Repeater applications shown here consist of (2) a training aircraft where both instructor and pilot require a fuel quantity indication; (3) its use in conjunction with single point refueling where an indication of total fuel quantity readable from the ground is desired (In this installation the primary indicator could be the totalizing indicator shown on the following page) and (4) an experimental aircraft using a duplicate instrument panel which will be photographed during flight.

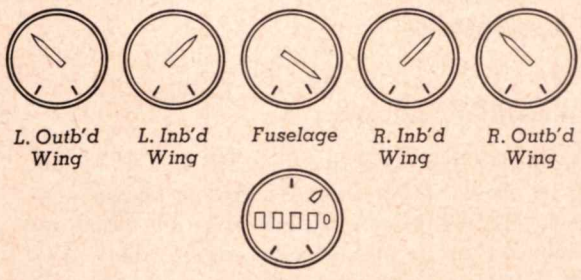




● ● Gaging Auxiliary Tanks

Where auxiliary tanks are used it is important for the pilot to know whether both tanks are feeding to the engine or whether only one tank is emptying. The later condition means that the fuel in the non-emptying tank is trapped and is not available to the engine. To provide the pilot with continuous indication of both left and right auxiliary tanks, two special "miniature fuel gaging systems" can be installed. Each system consists of a 1½ inch diameter indicator, a tiny silicon transistorized power unit (designed for 100° C operation) and the necessary tank units. By locating the left and right indicators side by side the pilot can tell at a glance whether the auxiliary tanks are emptying at equal rates. As soon as they are empty the pointer on the internal fuel system indicator will begin to move from its full position.

For existing airplanes, to which additional external tanks have been added, the miniature systems can be supplied in kit form. Panel space for the 1½ inch diameter indicators is easier to find than for the standard 2 or 3¼ inch diameter types. Likewise, the tiny transistorized power unit, requiring no shockmount and minimum accessibility, can be located anywhere between the indicator and the tank units.



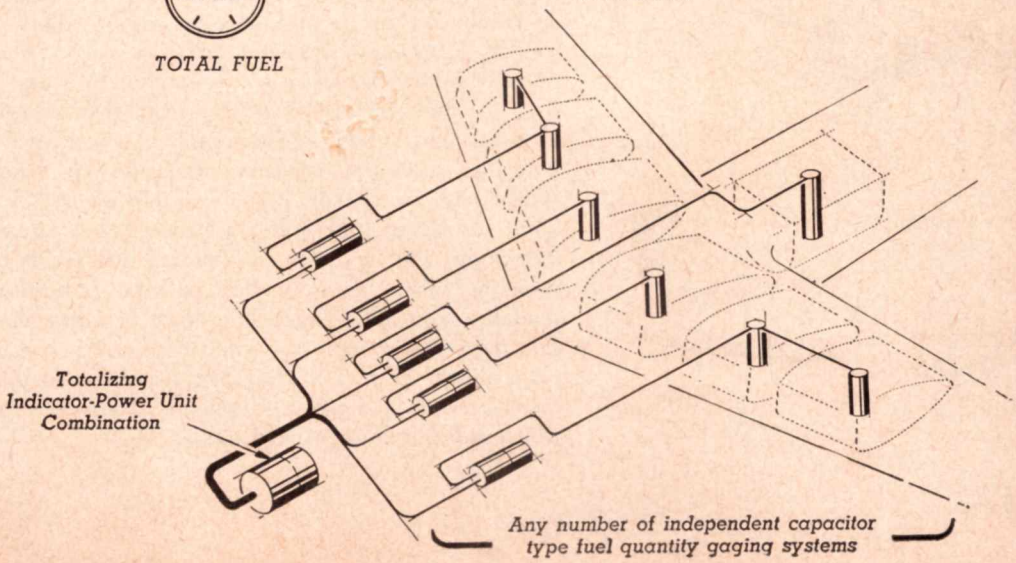
● ● Totalizing of Individual Indicators

For larger aircraft such as bombers, transports and lighter-than-air craft a complete picture of fuel distribution throughout the ship can be obtained from an indicator totalizing system. An example of the display provided by this system is shown to the left. The individual indicators are of the standard pointer type while the totalizer is a pointer-counter type. A direct numerical reading of total fuel is shown by the counter windows and the proportion of fuel remaining (¼ of total, ½ of total, etc.) is indicated by the pointer. Other dial types can be supplied to suit the requirements of different aircraft models.

A totalizing installation consists of

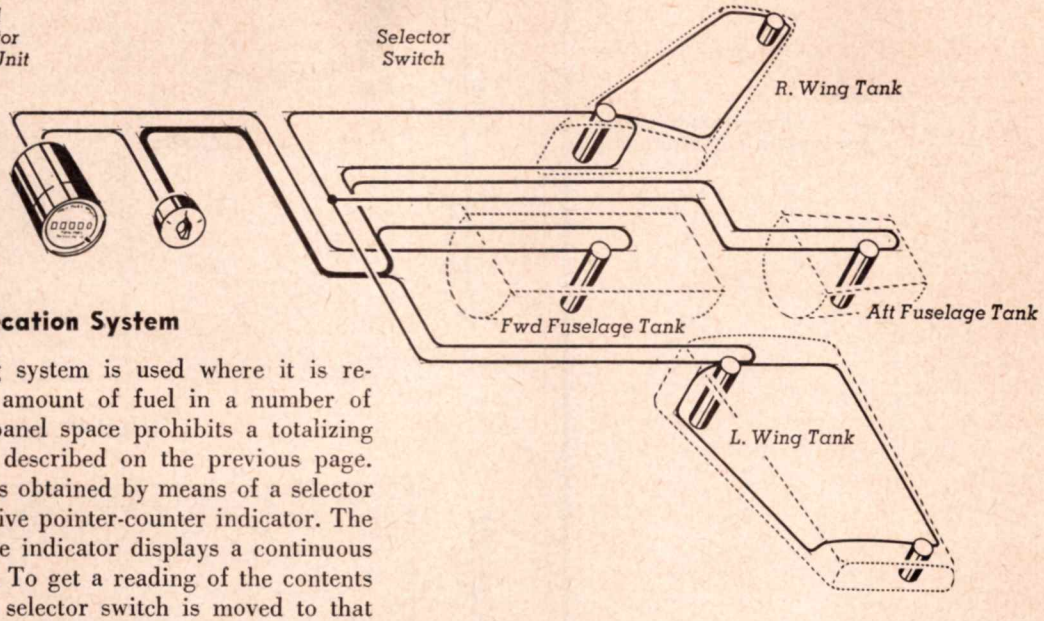
(1) any number of separate capacitor type fuel gaging systems.

(2) a totalizing indicator and power unit operating from auxiliary potentiometers located in the individual indicators.



Dual Indicator Power Unit

Selector Switch



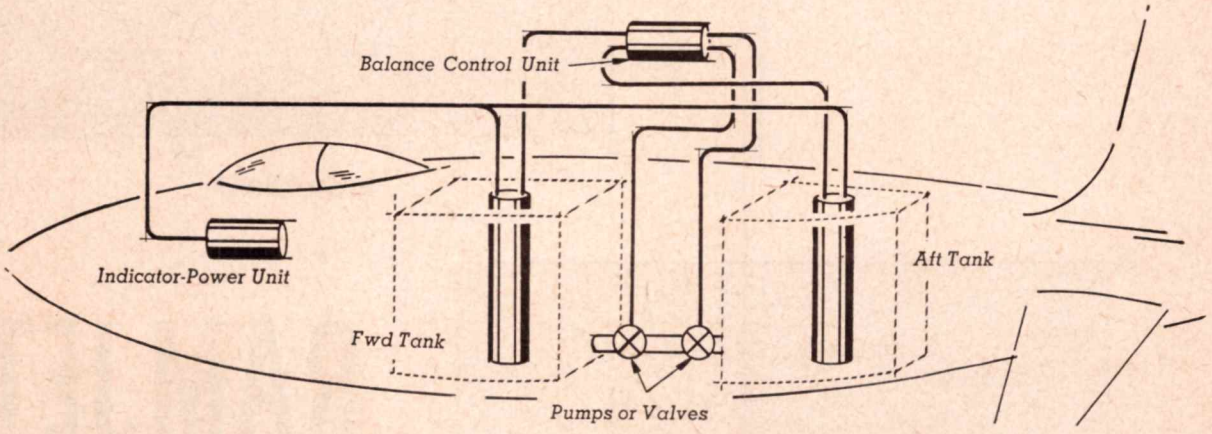
● ● Selective Indication System

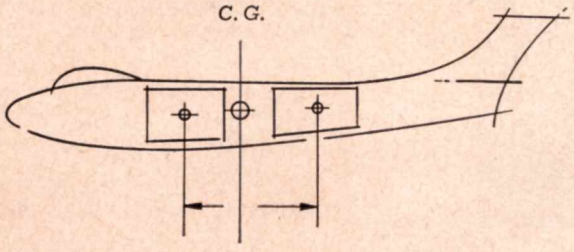
A selective gaging system is used where it is required to know the amount of fuel in a number of different tanks but panel space prohibits a totalizing system such as that described on the previous page. Selective indication is obtained by means of a selector switch and a dual drive pointer-counter indicator. The counter section of the indicator displays a continuous reading of total fuel. To get a reading of the contents of a single tank the selector switch is moved to that tank. The pointer section of indicator will then move to show the fuel in that tank.

Dual drive pointer-counter indicators differ from the standard type used with the totalizing system described on the previous page in that the pointer and the counter of the former are independent of each other. Separate self-balancing bridges operate each section.

● ● Center of Gravity Controls

The weight of the fuel carried by modern aircraft represents a substantial part of their total weight. Therefore, it is often necessary to closely adhere to a predetermined fuel usage program in order to maintain the proper center of gravity location.





An example of this is the airplane shown here where fuel quantity is to be indicated and also a predetermined quantity relationship maintained between the forward and aft tanks. To do this, one sensing circuit in each of the two tank units form opposite legs of a self-nulling capacitance bridge network contained in the control unit. The control unit continuously compares the amounts of fuel in the two tanks and when necessary actuates external devices such as pumps or valves to restore balance. The second sensing circuit in each of the tank units is combined in a standard fuel quantity gaging system. END

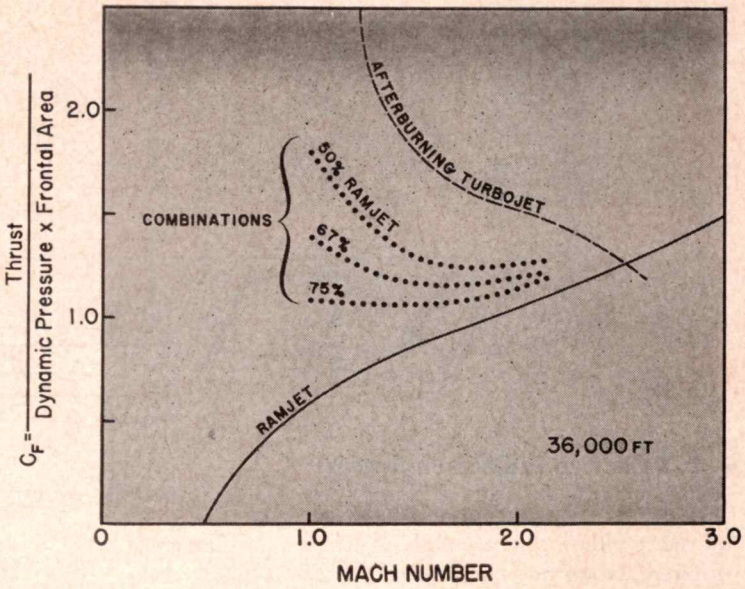


Figure 1—Thrust coefficients for powerplant combinations.

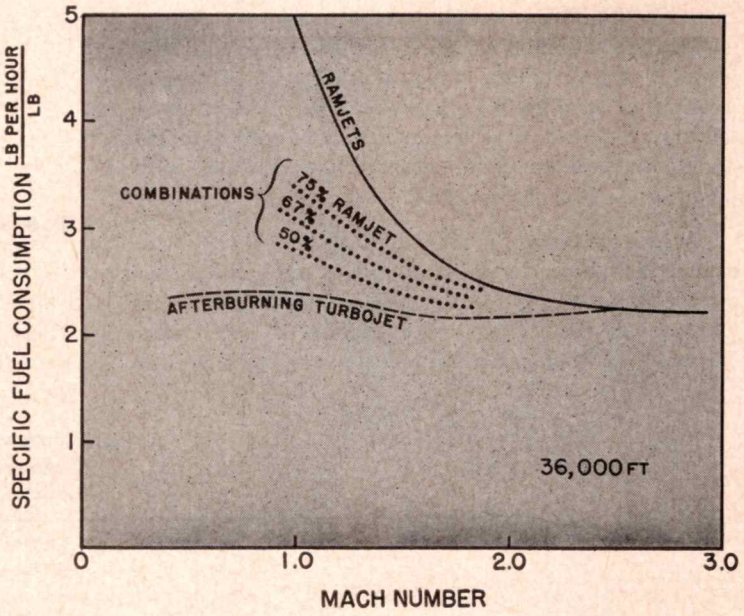


Figure 2—Specific fuel consumptions of powerplant combinations.

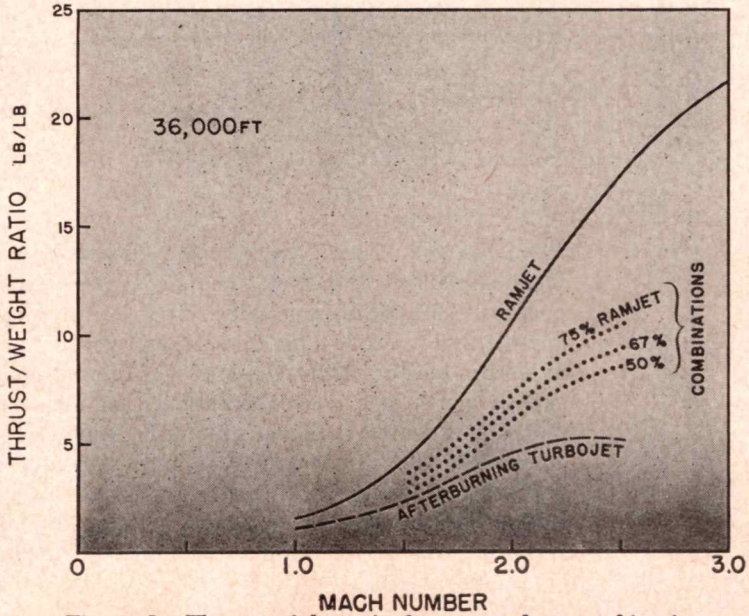


Figure 3—Thrust-weight ratio for powerplant combinations.

RAMJET-

JOSEPH FRIEDMAN
Chief Technical Engineer
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Van Nuys, California

TURBOJET POWERPLANTS

Can Extend Flight Regime

Performance figures indicate that suitable combinations of jet propulsion systems can lengthen aircraft speed range, increase ceiling, and push thrust-to-weight ratio of system to twice that of an afterburning turbojet alone.

THREE ENGINE TYPES are currently considered for supersonic propulsion: the rocket, the ramjet, and the afterburning turbojet. Except for high specific fuel consumption, the rocket engine initially appears to be the most attractive because of its high thrust-to-weight and high thrust-to-frontal-area ratios. Further study usually shows that after the first minute of supersonic flight, the combined weight of engine and fuel becomes increasingly larger for the rocket as compared with any of the air-breathing engines available. Consequently, the ramjet and the afterburning turbojet seem to fit better as principal tools for providing long duration supersonic flight.

The designer is faced with the problem that both the ramjet and the afterburning turbojet present operating difficulties at the opposite ends of the speed range. The ramjet cannot generate static thrust and is capable of only modest performance in the high subsonic range, whereas the afterburning turbojet experiences increasing difficulty in attaining efficient operation much above Mach number 2.0. It seems that the ramjet and turbojet tend to be complementary powerplants, and it is conceivable that by suitably combining the two, each could overcome the other's shortcomings.

• • Assumptions

In order to conduct this combination powerplant study, it is necessary to assume performance data that are representative of ramjets and afterburning turbojets. It is also necessary to state some generalized but representative airplane mission requirements, and set forth typical performance data for such airplanes, Reference 1.

For supersonic aircraft missions, it is assumed desirable from a military point of view to fly as high and as fast as practicable. Also, it is assumed necessary to cruise subsonically as efficiently as possible on dry turbojet engines with intermittent supersonic operation, in order to maximize the effective range of the airplane. For an airplane operating solely with afterburning turbojets, sufficient power for level flight at Mach 2.5 at 50,000 feet must be provided. Upon adding ramjet power to the aircraft, the turbojet frontal area is cut in half, this being the minimum size of dry turbojet that will allow high subsonic cruise in the vicinity of 40,000 feet altitude. With the establishment of the minimum size turbojet engine necessary for take-off, cruise and landing, the level flight ceiling of the airplane must be investigated with increments of ramjet engine power of one, two and three times the frontal areas of the reduced size turbojet.

• • Configurations and Performance

Figure 1 shows the thrust coefficients used in this study. Data are given for five cases: the solid line represents a variable geometry ramjet; the dashed line shows an afterburning turbojet; and the three dotted lines present the thrust coefficients for the three ramjet-turbojet combinations studied. The three percentages, 50, 67 and 75 percent ramjet, indicate the ramjet portion of the total powerplant frontal area. Thus the 50 percent ramjet curve is for the case where the ramjet represents half of the total powerplant frontal area.

Figure 2 shows the specific fuel consumptions for the same five cases. The 50 percent curve shows that adding an equal amount of ramjet frontal area to the afterburning turbojet does not greatly increase the specific fuel consumption in the transonic region and yet allows the turbojet thrust to be doubled at Mach 2.5.

Figure 3 shows the thrust-to-weight ratios for the five cases, and indicates the powerplant weight savings possible by the use of ramjet-turbojet combination. The first three Figures indicate that it is possible to postulate a ramjet-turbojet combination, on the order of 70 percent ramjet, that will have twice the thrust-weight ratio of the turbojet at Mach 2.5 without losing in thrust coefficient at that point, and yet have reasonable specific fuel consumptions at lower Mach numbers.

Figure 4 presents the drag coefficients for a hypo-

thetical supersonic aircraft. Superimposed upon these drag curves are the thrust coefficients of the afterburning turbojet and two of the ramjet-turbojet combinations. Both these combinations materially increase the level flight ceiling at Mach 2.5.

Figure 5 indicates the level flight ceilings for the three ramjet-turbojet combinations and the afterburning turbojet only. It appears that the 67 percent case may be of the most interest. Although the 75 percent ramjet case does show an altitude advantage over the 67 percent case, we may find ourselves in a region where ramjet combustion becomes difficult. Also, the 75 percent case involves a doubling of the original powerplant frontal area which may be impractical from an aircraft standpoint. On the other hand, the 50 percent case shows no altitude advantage below Mach 2.5, and hence is of little interest. It appears that the optimum combination of ramjet and turbojet power might be the case where about two-thirds of the powerplant frontal area is ramjet.

The foregoing analysis points out the attractiveness of the ramjet-turbojet powerplant combination for supersonic flight. The turbojet is used to overcome the low flight speed deficiencies of the ramjet. The turbojet is sized to provide sufficient power for takeoff, subsonic cruise and landing. Enough ramjet power is then added to give the desired flight ceilings at supersonic speeds. This results in an overall saving in engine weight, and in the ability to attain higher speeds and altitudes. The installation problem indicates that one of the lightest and lowest cost combinations may consist of an internally-mounted ramjet with small external turbojets.

• • Conclusions

It may be stated that:

1) A suitable combination of ramjet and turbojet can provide an integrated supersonic propulsion system capable of overcoming individual deficiencies of the component powerplants.

2) The use of ramjet power in addition to turbojet power will extend the speed range considerably above the turbojet placarded limit.

3) In cases where sufficient turbojets power is installed to permit supersonic cruise, the use of ramjet power will significantly increase the airplane ceiling.

4) Propulsion system weight will be minimized for the ramjet-turbojet combination as its supersonic thrust-to-weight ratio is approximately twice that of an afterburning turbojet. END

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2. Harned, H. S., *The Application of the Ramjet to Aircraft Propulsion*, Marquardt Aircraft, December 1952.

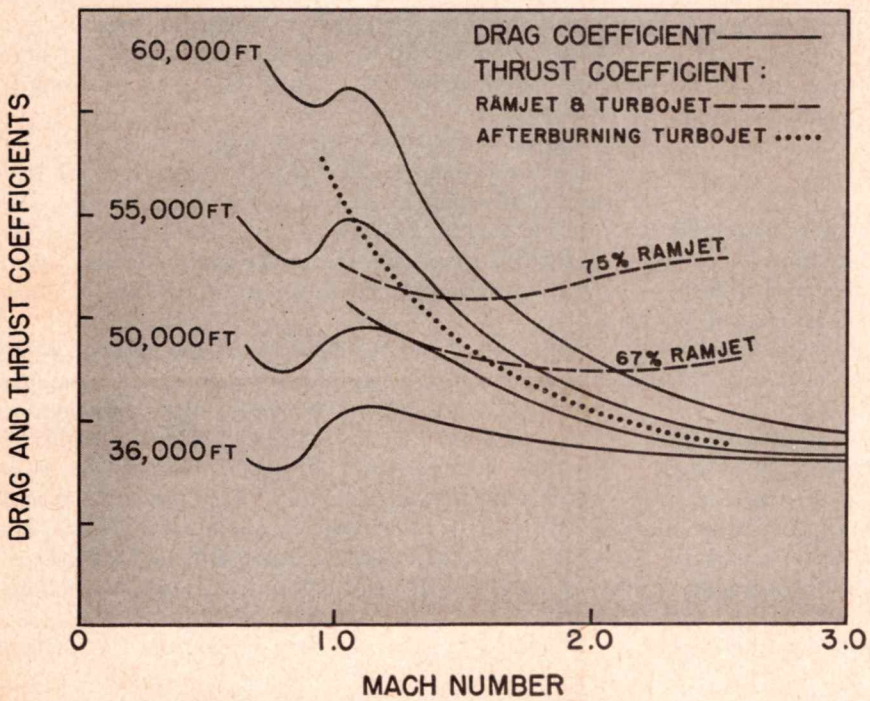

Figure 4—Thrust and drag coefficients.

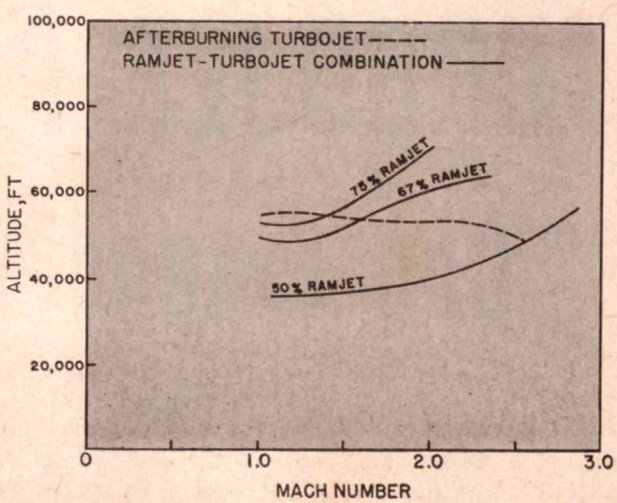

Figure 5—Level flight ceilings.

Fundamental aerodynamic data derived from Lippisch wind tunnels and high-speed cameras that permit photographing time sequence of airflow events.

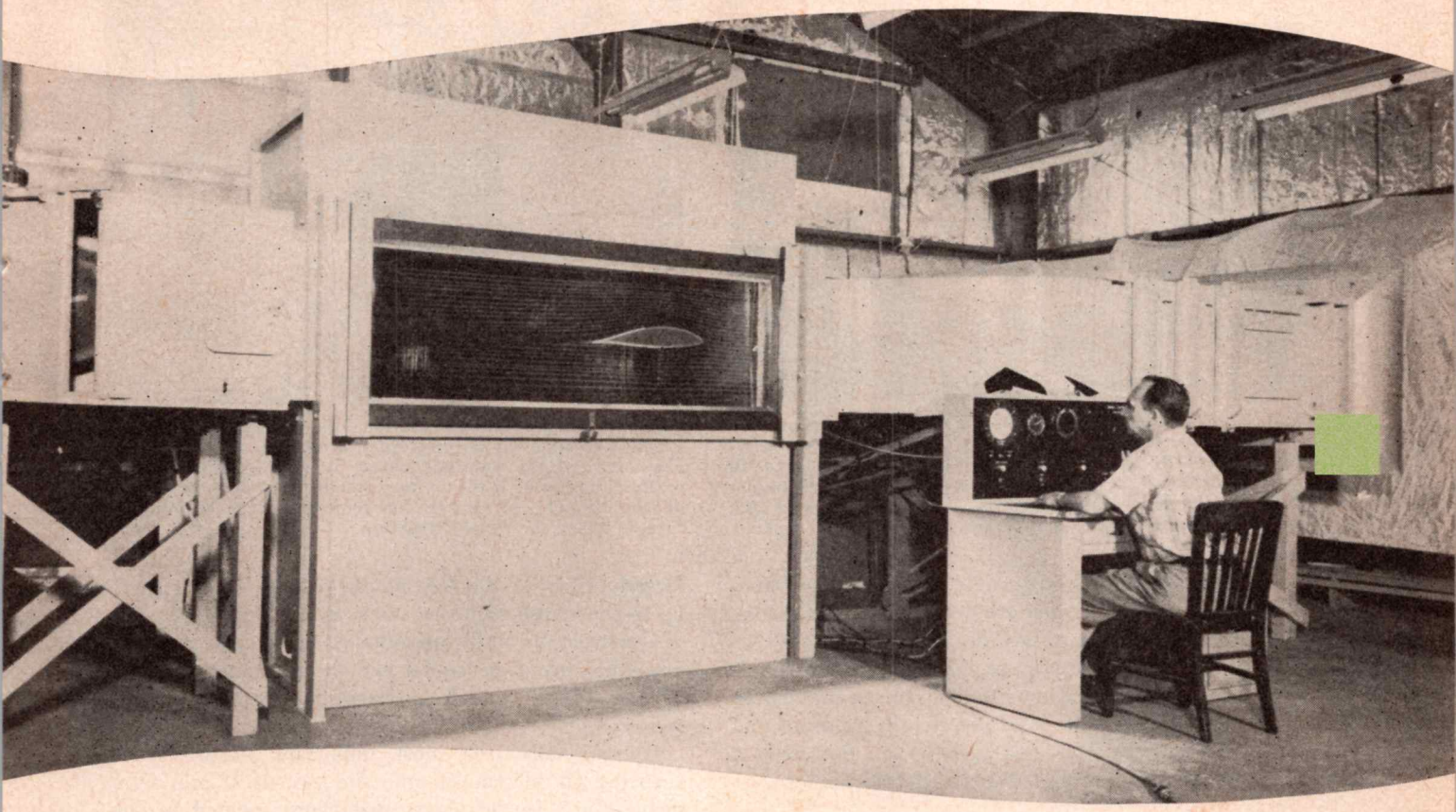

Figure 1—Two-dimensional smoke tunnel. Air flows through the tunnel from right to left. At the right-hand of the picture is the inlet, the silencer chamber, and the nozzle leading the air into the test section. At the left-hand of the picture is the suction chamber partly opened and the blower at outlet. In front of the tunnel is the control panel where the tunnel operator can adjust the tunnel velocity, the model attitudes, and the illumination of the test section.

Airflows Studied in Miniature SMOKE-JET WIND TUNNELS

EQUIPMENT that makes it possible for engineers to easily watch air-flow phenomena has been developed under Dr. Alexander M. Lippisch, Director of the Collins Aeronautical Research Laboratory. The unique wind tunnels used in this work were created as a by-product of classified projects sponsored by the Office of Naval Research.

The Lippisch system combines the use of smoke streams for the marking of the flow around airfoils, and high-speed motion pictures. Two separate types of wind tunnels are used in these studies, one for two-dimensional observations, the other for three-dimensional observations. The two-dimensional tunnel functions with an operating chamber three inches wide. Both sides of this tunnel are plate glass, Figure 1. Cutaway sections of model wings and other study shapes are locked between the glass walls. Visualizing air flows in this way provides a realistic reproduction of conditions as they exist around corresponding sections of wings on actual aircraft.

Jets of smoke are released at one-inch intervals along the length of the tunnel. Incoming air, which has been strained and accelerated to assure a minimum of extraneous turbulence, carries the smoke

Smoke-Jet

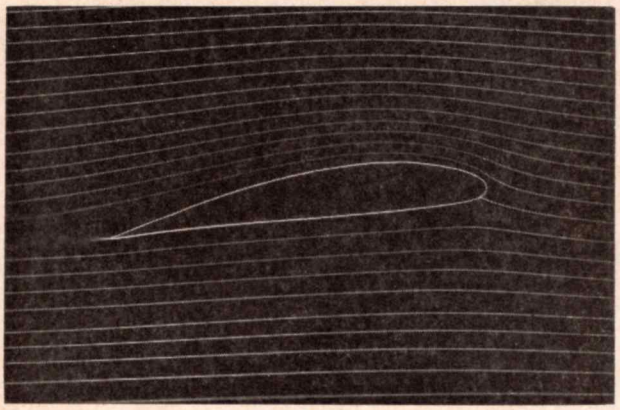

Figure 2—Flow picture around an airfoil section taken from the two-dimensional smoke tunnel shown in Figure 1. Local velocity and pressure variation may be noted by changes in smoke filament spacing. Closer spacing indicates higher velocity and lower pressure, as may be seen over the upper surface near the leading edge of the airfoil section.

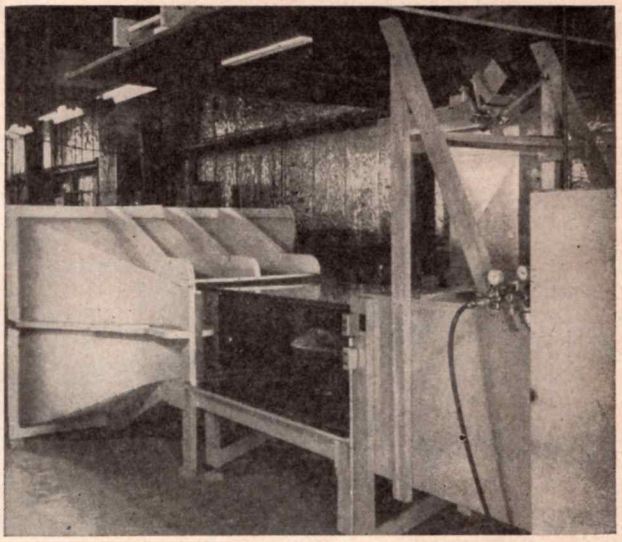

Figure 3—A partial view of the three-dimensional low turbulence tunnel. At the left-side, a portion of the silencer chamber and the entrance nozzle is visible. The channel at the right side leads to the diffuser and blower section of the tunnel. A camera for photographic recordings is located above the tunnel structure.

streams across the viewing field in straight, ribbon-like lines. As air streams are deflected by the model, the layers of smoke are also shifted to trace the airfoils in clearly visible patterns, Figure 2. The models within this two-dimensional tunnel can be rotated to change the angle of attack of the airfoil. Ailerons and other movable sections can also be manipulated at will from the observer's controls of this tunnel.

● ● Three-Dimensional Tunnel

The three-dimensional tunnel is three feet wide by two feet high, Figure 3. It is built to contain a scale model of a full wing plus a portion of the cutout section of the fuselage. Controls are also provided to change the angle of attack for the models in this tunnel.

The three-dimensional tunnel was designed specifically for research on boundary layers. In this work, smoke streams are released from holes in the leading edge of the model's wing and swept back onto the boundary layer to make the surface-flow visible.

Both tunnels operate with relatively low air speed—the three-dimensional tunnel airflow is 40 feet per second, while the two-dimensional model operates up to 75 feet per second. In the lower-velocity three-dimensional tunnel, the full process of releasing smoke along the leading edge of the wing, the forming a laminar flow along the leading edge, and the flow pattern going through the transition stage into turbulence, takes only about a fiftieth of a second, Figure 4.

With a Kodak high-speed camera, the smoke trails are photographed at speeds ranging from 1500 to 3200 frames per second. Projected at normal speeds, these pictures have the effect of slowing the motion more than a hundredfold. Even then, the engineers frequently find the movies too fast for accurate observation and prefer to look at their movies a frame at a time. For very detailed study, they order enlarged prints of the key movie frames, setting them up in time-lapse sequence strips as working references.

Construction and operational techniques for the miniature two-dimensional and three-dimensional tunnels are close enough to warrant only a single description.

Operationally, the most important feature is to keep the air introduced into the tunnels at minimum turbulence. In this way, turbulence created in the tunnels' viewing fields can be attributed with validity as having been created by the test bodies over which the air currents flow.

To accomplish this minimum turbulence, the designer uses a high contraction ratio in the air intake, and screening chambers that break up existing turbulence patterns and smooth the air streams. The nozzle of the two-dimensional tunnel produces a 20:1 contraction ratio. In the wider three-dimensional model, it was found practical to go only to a 7:1 ratio.

● ● Photography

Smoke in the tunnels is of paraffin oil derivation. Using a method devised by British scientists, the Lippisch group boils mineral oil, forces it with compressed air through an orifice in the heating chamber and then cools it with another air blast. The paraffin smoke has provided the most effective photographic results and has given the least trouble operationally with respect to clogged release holes. Air for the tunnels is pulled by exhaust blowers.

The photographic end of this research project called for almost as much attention as the construction and engineering. The photographers have a fleeting, translucent subject to be photographed against a jet black background. This makes it impossible for them to apply one of the first rules for normal high-speed movies—put as much light in as you can from every conceivable direction and use as many reflective sur-

faces as you can to multiply it. Under these conditions, the smoke would fade away to nothing.

The photographers work with intense, one-sided lighting. All illumination is either in front of or behind the subject, since both front and back lighting cuts the visibility of the photographed image. In the two-dimensional tunnel, the light is from behind the subject, with fixtures placed above and below the viewing field. A velvet backdrop behind the lights provides the necessary black background. In the three-dimensional work, light is thrown from in front of the subject, usually with fixtures placed above and below the camera. This tunnel is glassed on top and one side to permit observation and photography, Figure 5.

The Kodak high-speed camera used in this work can operate at speeds up to 3200 frames per second. The camera shoots its entire 100-foot roll in 1.3 seconds when it is operating at top speed.

Another of the more interesting photographic problems was the figuring of exposures. At these speeds and under these conditions, meters and measurements are useless. After considerable experimenting, the photographers were able to form a fairly dependable rule-of-thumb method. They bring a sheet of their regular movie film leader across the lens aperture in shooting position. When they can see a clear image of the smoke through film and emulsion, they know they will get a usable picture at 1800 frames per

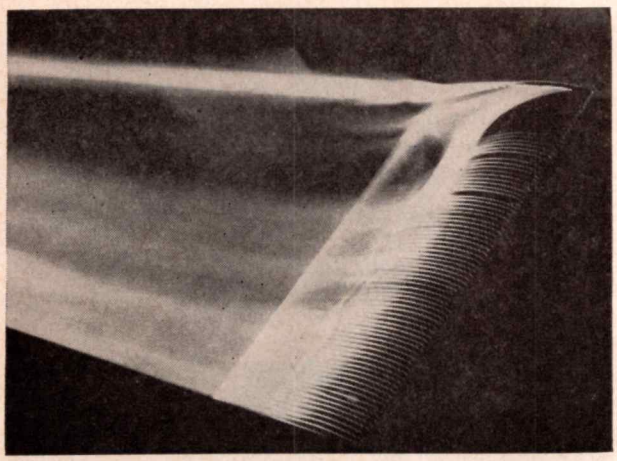

Figure 4—Flow picture from the three-dimensional low-turbulence tunnel shown in Figure 3. The photograph shows the surface flow configuration on a rectangular wing, camera shutter speed 1/50 second. Smoke filaments were released at the leading edge of the wing. The diffusion of the filaments shows the transition region from laminar to turbulent boundary layer. To see the local flow near the wing tip and the formation of the tip vortex, technicians released smoke filaments along the tip. The in-flow of air from the wing tip into the sub layer can be observed.

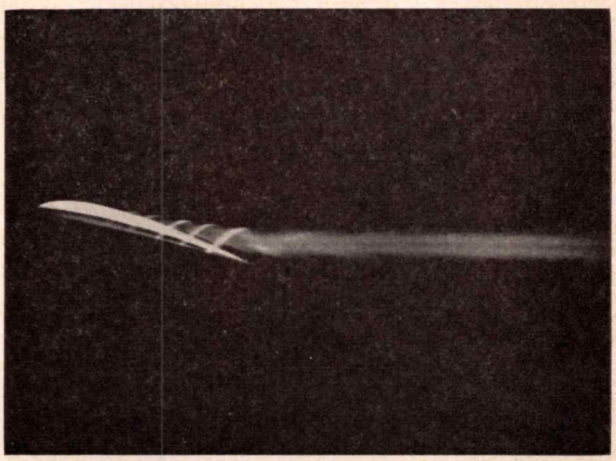

Figure 5—Flow around the wing tip of a rectangular wing taken in the low-turbulence three-dimensional tunnel. This picture shows the formation of the wing tip vortex generated by the circular flow around the wing tip. The core of the vortex is represented by the dark line in the center of the smoke trail.

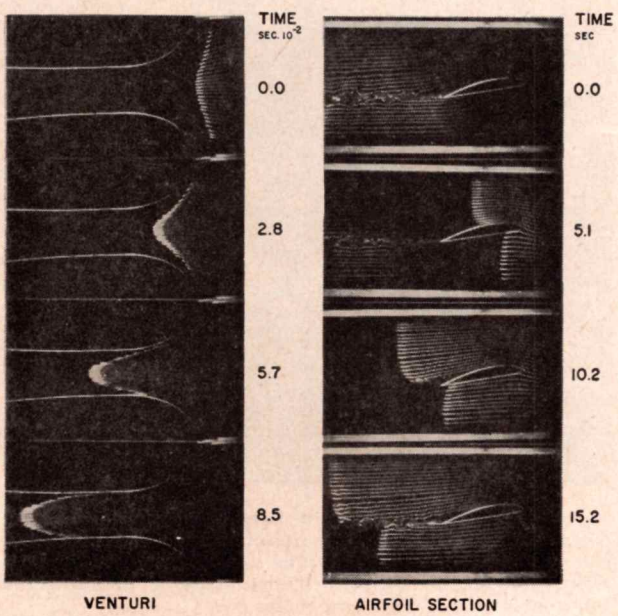

Figure 6—Sequence photographs of time lines in two-dimensional flow fields.

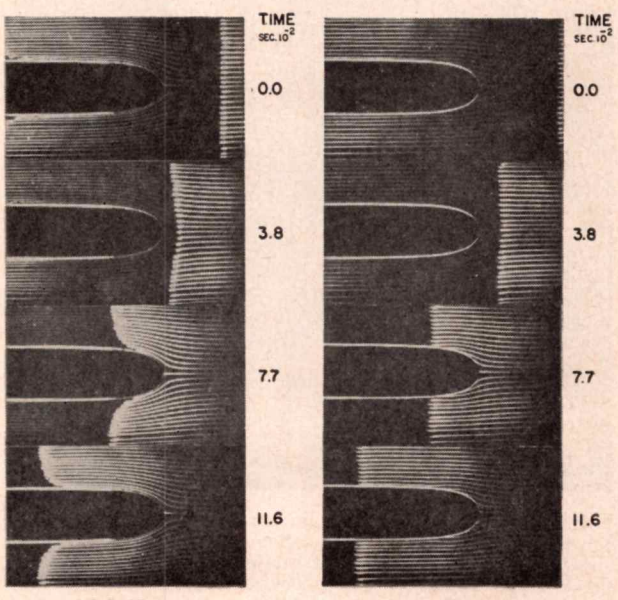

Figure 7—Sequence photographs of time lines in a two-dimensional flow field, around a half body with and without leading edge suction.

second. Other shooting speeds can be gauged by adjusting the lens aperture accordingly.

With the two-dimensional tunnel, the engineers have made what is probably the first connection between the patterns of air flow over a wing surface and time. In time-line studies, they have released smoke into his two-dimensional tunnel in puffs, creating a frontal line in the air flow which is easily discernible on high-speed film, Figures 6 and 7.

In the vicinity of a model in the tunnel, the originally uniform flow changes into a flow field with different velocities. Along each flow line, made visible here by a smoke line, the speed increases or decreases and a particle of air traveling along this line will be accelerated or retarded in comparison with another particle flowing along the next flow line. Therefore, the velocity field induced by the model causes a change in the shape of this smoke front which enters the view chamber as a straight line and begins to deform as it approaches the vicinity of the model.

For the first time, however, the observation of the time line, which such a smoke front forms, has shown that those air particles which were initially in a straight line do not rejoin after passing over the wing, and that there is a definite shearing between the upper and lower part of the time line passing over a wing section which produces lifting flow, Figure 6.

Flow patterns on symmetrical streamlined bodies show another phenomenon when viewed through the course of the time lines. Calculating these time lines from the ideal frictionless flow as represented in the potential flow theory unveils the fact that the flow front never reaches the surface of this body. Theroetically—even without any friction—the time to form the flow line that surrounds the body is infinite.

The time line embraces the model and is stretched out more and more as the upper and lower branches of the time line proceed farther over and behind the model. A small layer of untouched air is always left between the outer flow and the model, and this layer is then accelerated by the viscosity forces between the outer flow and the dead air on the surface of the wing or model itself. This is the boundary layer, which not only causes the friction drag on aircraft surfaces, but is heated up by this friction at speeds above the speed of sound.

If the shear between the air layers is to be avoided, resulting in a flow that has no boundary layer forma-

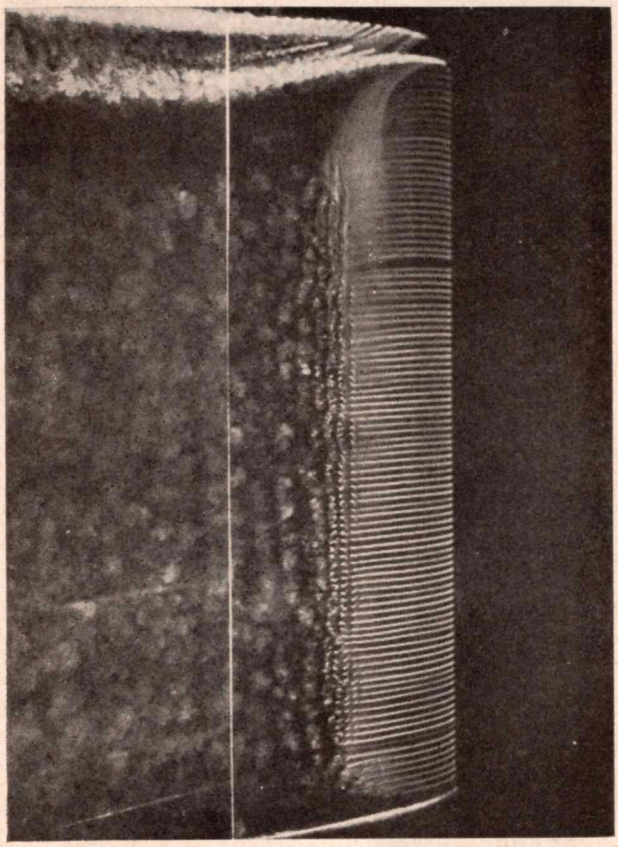

Figure 8—Surface flow on a rectangular wing taken in the low-turbulence three-dimensional tunnel. This photograph shows generally the same flow condition as Figure 4, but was taken at an exposure of 1/25,000 second. With such short exposure one can observe the flow phenomena in the transition region of the boundary layer. The surface flow first forms waves which, after a few oscillations, overturn and dissolve into random turbulent motion.

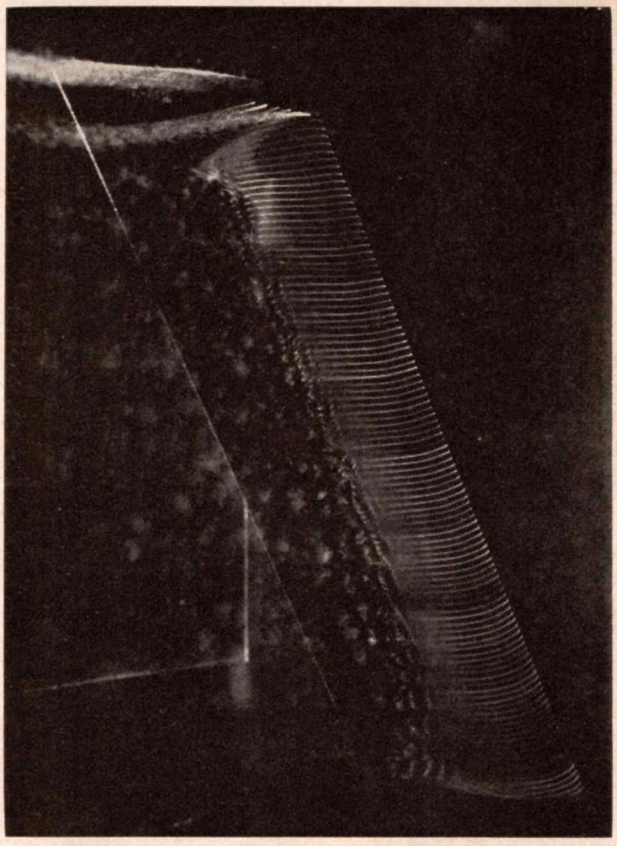

Figure 9—Surface flow on a 30° swept-back wing of constant chord. This picture had an exposure of 1/5000 second, and shows the wave formation and the transition of the boundary layer, and when compared with Figure 8 indicates the influence of the small sweep-back.

tion, the time line must be kept straight from the beginning. This could be accomplished with suction through a porous surface on the leading edge of the airfoil. A simple test in the two-dimensional smoke tunnel has proved the validity of this concept and could pave the way for important improvements in subsonics as well as in supersonic speed range.

In the three-dimensional tunnel, the engineers have been able to make visible the process of transition in the boundary layer from a laminar flow along the leading edge through a series of oscillations and into the transition of turbulence. This process has been effectively isolated through high-speed movies of a single ribbon of smoke as it passes back over wing surfaces. In this presentation, the flow of the boundary layer resembles closely that of an ocean. The first change in the laminar surface is a series of oscillations that build up like rolling waves. At length, in the transition stage, the oscillations roll over like breakers in ocean surf, breaking up into random turbulence. The photographs in this series are believed to be the first of their type ever presented to aeronautical science and industry, Figures 8-11.

Considering their research potentials, the Lippisch wind tunnels carry a low price tag. The two-dimensional tunnel costs about $20,000 to put together while the 3-D version runs in the neighborhood of $40,000. The junior, desktop model which would sell to schools and colleges will probably cost around $1000.

Although the Lippisch wind tunnels and accompanying photographic presentations are still in their early stages, at least three important practical applications can already be foreseen for these new tools:

• • Conclusions

1) Education. Visual presentation can be important in establishing a sound foundation of knowledge among scientists entering the field of aerodynamics. Visual impressions imposed by this type of teaching tool will create a more lasting impression than diagrams or other explanations.

2) Studies of lift properties of aircraft structures at low speeds.

3) Studies of what causes heat in airplanes and how it can be eliminated. Supersonic conditions may not be necessary to approach these problems. Heat is created and transmitted in the boundary layer. At the leading edge, where the problem originates, air speed is zero no matter how fast the aircraft is moving. END

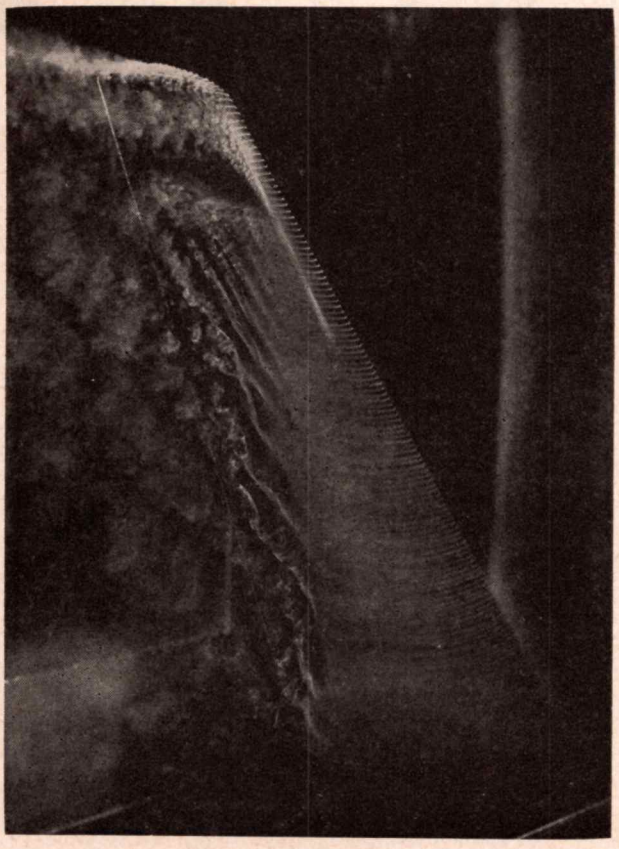

Figure 10—Surface flow on the leading edge of a tapered wing of 45° sweep-back. This picture, taken at an exposure of 1/5000 second, shows the influence of the larger sweep-back on the boundary layer transition and the development of the leading edge vortex at the wing tip region. It can be seen that spanwise flow towards the wing tip in the boundary layer is generated by the spanwise pressure distribution along the swept-back wing.

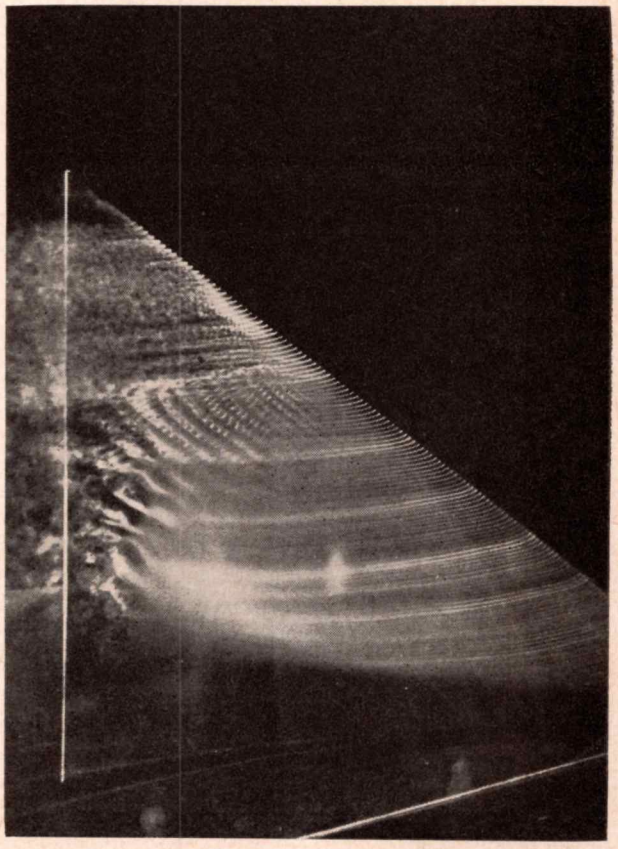

Figure 11—Surface flow over a delta wing of 60° sweep-back taken in the low-turbulence three-dimensional tunnel of the Collins Aeronautical Research Laboratory. This picture shows the strong interference of the sweep-back on the behavior of the boundary layer with a marked discontinuity between the full turbulent region at the wing tip, a transitional region at the center of the wing, and an almost completely laminar region at the wing root. It is of interest to note that the waves in the boundary layer are parallel to the leading edge of the wing.

SYSTEMS ANALYSIS For Weapons And Missiles

WILLIAM F. WRIGHT
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and

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Senior Research Engineer
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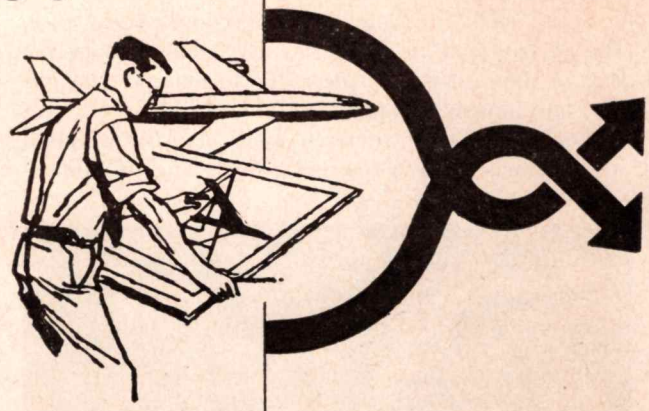
The procedures rather than the concepts of systems analysis are stressed. The article gives the practical engineer an insight into the mechanics of system-analysis operation from the contractor's and the military's viewpoints.



THE WEAPONS SYSTEM CONCEPT arises from a broad philosophy called the *system approach*. To the practical engineer, the system approach is a way of thinking about equipment and its use so that every design and development drawing, every specification, every training and operational schedule, every production schedule is produced with a common goal in mind: namely, the most effective overall use of that equipment. The system, therefore, must be planned as a whole, it must be engineered as a whole, it must be programmed on a system basis; finally, management must be system conscious so that all the components of the system, from spark plugs to trained personnel to air bases, must be ready, available and operational at the proper time.

The phrase "most effective overall use" implies an optimization of quantities involved in the design, performance and production of the system. That is, the ultimate system that is produced should be the best possible for the amount of money or effort to be expended. The methodology, by which optimal designs of the air vehicle, ground-based navigation and control, training, supporting, armament, operational base, manpower supply and logistic systems are set up, as well as the pricing and scheduling for these systems, is called "weapon system analysis."

• • Use of System Analysis

The specific aims of system analysis, then, from the contractor's point of view are to provide facts and recommendations concerning the optimal design, operation and production of a complete weapon system. Within these aims seven major objectives are definable:

1) To establish the technical, economic, operational and logistic capabilities and limitations of weapon systems.
2) To specify operational environment, tactics and logistics as a basis for weapon design.
3) To optimize weapon system design parameters.
4) To evaluate the suitability of sub-systems and their components for specific tasks.
5) To generate specific performance requirements on each component in the entire system, from

development through production, logistical and training schedules.

6) To conceive new systems or sub-systems or improvements that will satisfy requirements disclosed by the system studies.
7) To recommend operational uses of the systems or any part of them.

The methods of system analysis are primarily analytical; consequently, activities usually begin with a complete formulation of the problem in terms of approach, objectives, assumption, scope, general methods to be employed and effort to be expended. Information must be gathered from any and all sources, including those in military, technical, economic and social fields. A critical analysis and evaluation is then undertaken in order to determine the capabilities and limitations of the system under realistic operational conditions. Specific examples of factors that must be considered in this analysis are:

1) Engineering feasibility.
2) Development schedule and cost.
3) Production capability (including manpower, factory space and facilities required).
4) Production cost.
5) Field operations (including maintenance).
6) Logistics.
7) Military effectiveness.
8) Capability for evolutionary growth.
9) Flexibility and versatility.

Optimization of the system parameters is usually achieved in a sequence of steps such as these: selection of one or more measures of effectiveness of the weapon system; examination of the variation of such measures of effectiveness as functions of the system parameters over a wide range of conditions; selection of system measures of cost and examination of an enemy's probable tactics and his offensive or defensive equipment. Finally, every study of a problem that is successful in reaching the objectives laid out in the problem formulation results in conclusions and recommendation derived from the results of the study. These end results provide a quantitative basis for decisions in weapon research, development, production and utilization.

Based on an analysis of factors such as a possible enemy's target complex, his offensive and defensive system capabilities and potentialities, and an examination of geopolitical factors, a set of requirements is presented by the Air Force to various contractors in a request to bid on a proposal to provide or develop a weapon system that will satisfy these requirements within a specific time period. These requirements are usually incorporated in an Air Force document called a GOR (General Operational Requirement). Emphasis is usually placed on an operational need and not the means by which these needs are to be satisfied. Where appropriate the GOR includes such related items as intelligence position, combat situation and potential, organizational status and growth. It may also include descriptions of factors such as logistics, operating environment and training needs.

As soon as the contractor has decided to submit a proposal in answer to the Air Force request, his system analysis personnel are usually given the job of putting together the optimal weapon system. It should

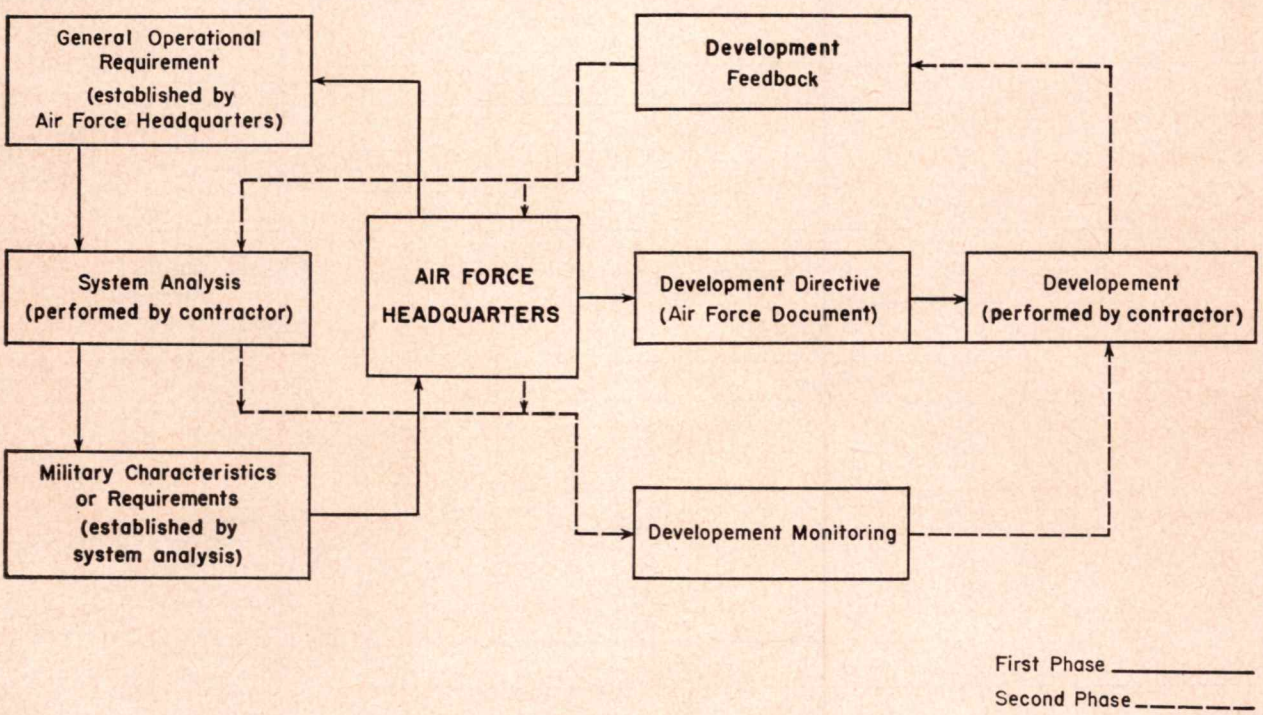

General Operational Requirement (established by Air Force Headquarters)
Development Feedback
System Analysis (performed by contractor)
AIR FORCE HEADQUARTERS
Development Directive (Air Force Document)
Developement (performed by contractor)
Military Characteristics or Requirements (established by system analysis)
Developement Monitoring
First Phase
Second Phase

Figure 1—Simplified functional diagram illustrating flow of information in typical system analysis.

be also understood that this process is occasionally reversed, that is, the contractor will foresee defense needs for certain equipment or research along a certain line, needs that may not have been investigated by the Air Force and for which no GOR may exist. In that case, in order to generate Air Force interest, the contractor may submit an informal proposal.

In this first phase, system analysis is preliminary in the sense that the contractor may take no further action on the system he is proposing until he prepares a set of weapon system specifications in accordance with the requirements of Air Force Specification MIL-D-9310, Figure 1.

• • Conducting Typical Analyses

For performance characteristics the GOR usually provides either specific values or permissible ranges within which the optimal values may be selected. For the purpose of illustration we now present brief discussions of those items that may appear in a weapon system GOR. A GOR may not mention a particular item, in which event it is either not applicable or is left to the contractor to specify.

1) *Speed* may be given either as specific Mach number, as a permissible range, or as a speed regime (subsonic, transonic, supersonic or hypersonic).

2) *Warhead* is usually specified by type (or alternate types) and weight. Of course, choice of type and destructive capacity of warhead are intimately related with the accuracy required and the nature of the target or target complex. The requirements of warhead type and accuracy, therefore, must be consonant with each other and with the target complex specifications.

3) *Accuracy* is usually specified in terms of an acceptable CEP (Circular Probability of Error) if the objective is a surface target. CEP is defined as the radius of that circle within which 50 percent of all impact points will fall. For air targets or mobile surface targets, the accuracy may be stated in terms of acceptable rms mis-distances.

4) *Reliability* is usually required to be high. Very high reliability is often quoted but, it must be realized, the reliability that is finally accepted is often a compromise based on need and expediency.

5) *Range* is usually specified in terms of minimum distance between launching point and target.

6) *Guidance system* specifications depend to a great extent on the nature of the system. Where the type of vehicle, guided missile or manned aircraft, is not stipulated it is likely that the guidance system also will not be specified. Proposal of a particular guidance system depends on difficulties of fabrication, state of the art, types of targets, types of launching systems, training, testing difficulties and other factors.

7) *Type of aircraft* may or may not be specified depending on system mission. If the mission

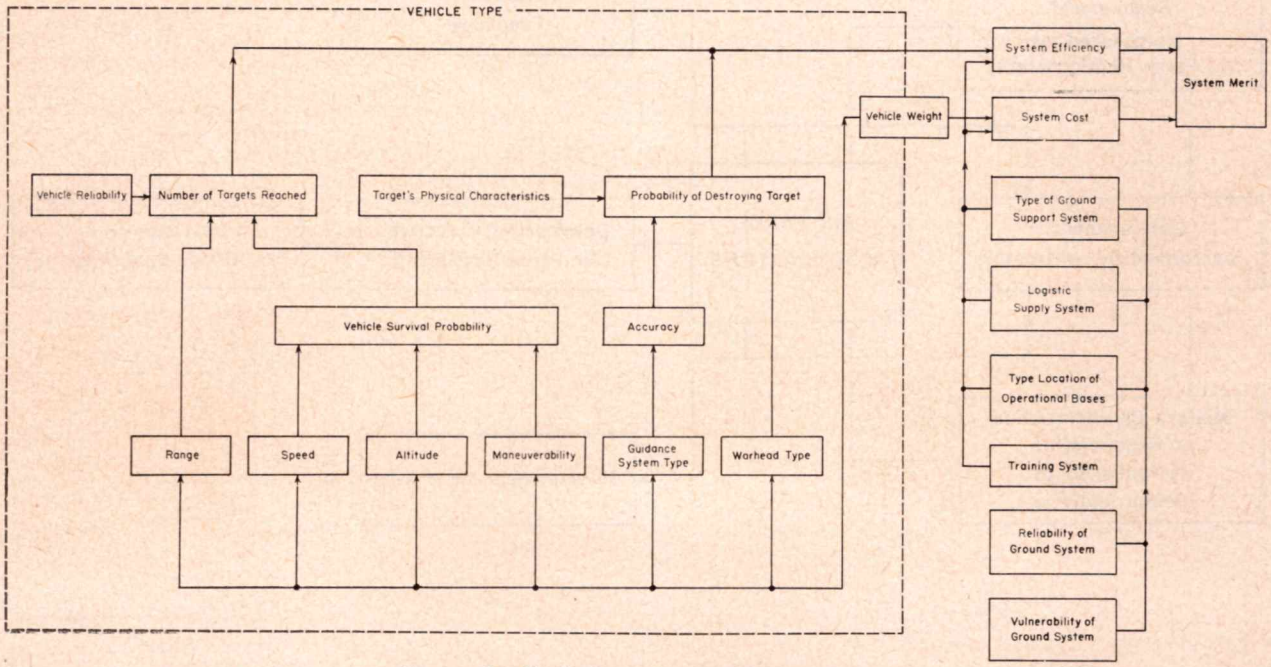
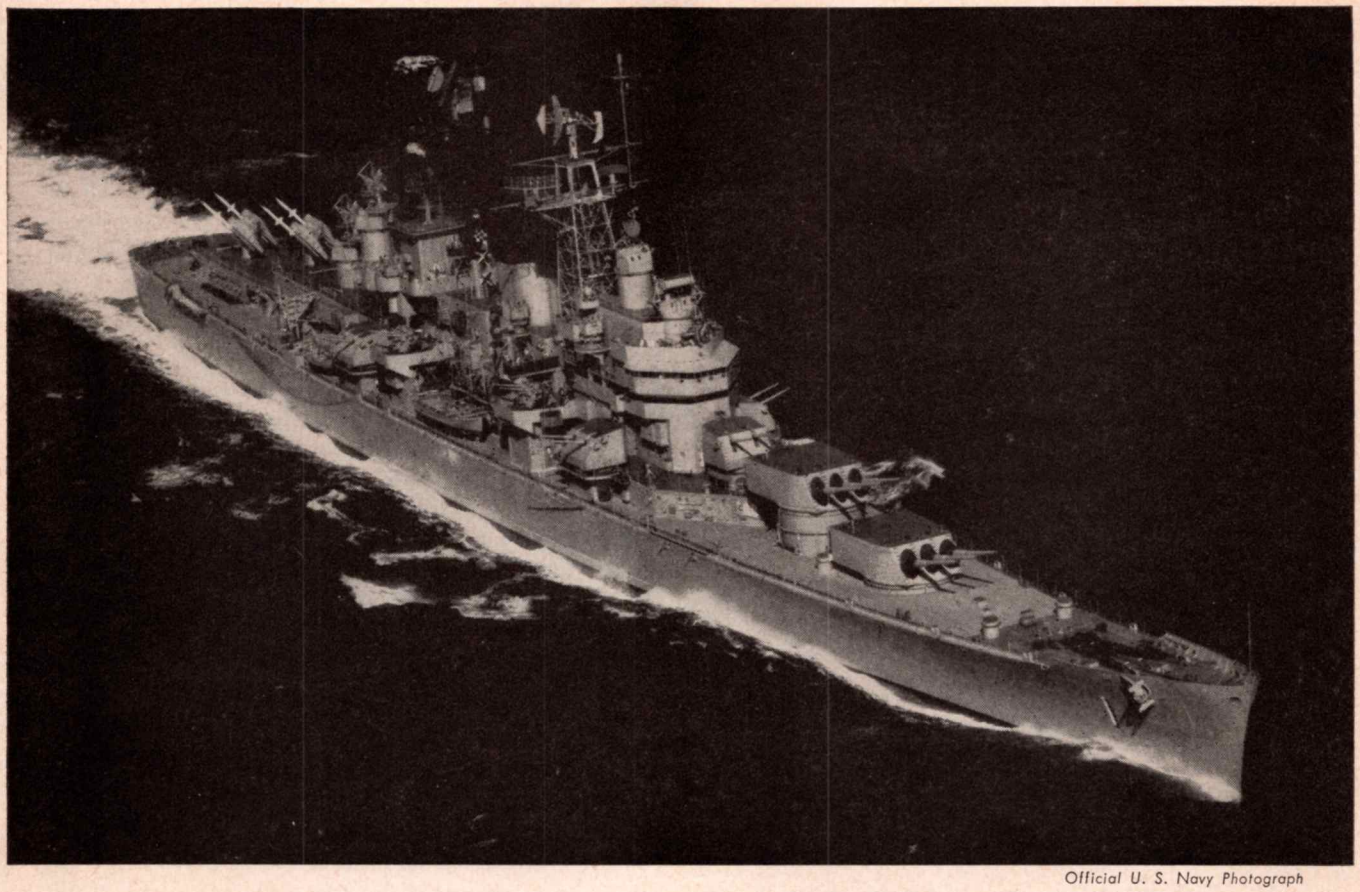


Figure 2—Evolution of a weapons system in the course of a system analysis.



Official U. S. Navy Photograph

The U. S. S. Boston (CAG-1), the Navy's first guided missile cruiser, with Terrier Missiles and their launchers at the stern.

NAVY BUREAU OF ORDNANCE DEVELOPS WEAPON SYSTEMS FOR USE AGAINST ATTACK BY SEA OR AIR

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The Research and Development Division of the Bureau of Ordnance has the responsibility of initiating and coordinating the research and development of the many projects which result in such end products as guided missiles, homing torpedoes, aircraft laid mines, and the launching and control systems for these weapons.

The job of guiding a key element of a modern day weapon system from the idea stage to the ready-for-combat stage involves a wealth of technology—drawing upon the skill, farsightedness, and courage of responsible scientific and technical personnel in the Bureau of Ordnance and its laboratories, and their counterparts in universities and industrial organizations.

This is one of a series of ads on the technical activities of the Department of Defense.

103

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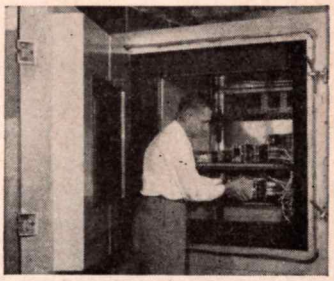

Ford Instrument Company engineer placing equipment designed for Navy instrument in one of the environmental test chambers.

ENGINEERS

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consists of the delivery of air-to-air rockets against bomber targets, for instance, the launching craft will probably be specified exactly. However, if the mission is the long-range bombing of surface targets, the choice of a particular aircraft type is usually the crux of the problem.

8) *Powerplant and fuel* choices are usually tied in closely with aircraft or missile choice. In a GOR these may or may not be specified completely, or some partial qualification may be employed; for example, if a turbojet powerplant is suggested by the contractor he may be constrained to use an easily obtainable fuel.

9) *Survival probability*, like reliability, is generally required to be high. Again, a compromise may be necessary because of need and expediency. The probability of survival of operational bases and logistical supply systems may also be treated in a GOR.

10) *Targets and/or target complex* may be described in general terms. For example, the target aircraft may be referred to as "a bomber of the B-52 type." Similarly, a surface target complex may only be referred to in terms of type (for example, enemy airfields), size (equivalent diameter), hardness (structural features) or dispersions (average distances between centers of targets).

Other system features will naturally be considered in relation to those items. These are important but secondary features that may not be explicitly discussed in a GOR. Examples are: simplicity of operation; storage life requirements; storage condition requirements; minimization of costs of resources; minimization of need for new, unique or complex facilities; minimization of vulnerability to enemy countermeasures; maximization of efficiency of transportation system, and minimization of risk to friendly personnel and equipment.

• • System Analysis and the Engineer

At this point, the very outset of the analysis, a certain amount of engineering judgment must be applied in setting up basic operating assumptions and in settling on a figure of merit, sometimes called "system effectiveness." The engineer's judgment is not usually mentioned in articles on the subject of system analysis and the practical engineer is likely to feel that every phase of the subject is cut and dried. Nothing could be further from the truth.

In addition to picking his assumptions carefully, the engineer must decide on the methods to be used at any one stage and the amount of effort to be devoted to that stage because they are influenced by the accuracy required and the relative importance of these answers. It requires judgment based on experience to be able to foresee whether the final outcome will be sensitive to the accuracy of results at any one stage. The analyst must exercise his judgment in cutting away unessentials in order to get at the heart of the matter.

The role of judgment and experience in systems analysis becomes obvious if one examines the parameter that plays a central part in the whole analysis, namely, the figure of merit, or the yardstick by which one system is compared with another. Suppose two or more systems are proposed, each of which can perform the same mission with the same efficiency. Clearly one would use that system that costs least or that could be delivered earlier. On the other hand, if the costs are about the same, but the efficiencies differ, one would use the system that had the greatest efficiency. However, it rarely occurs that the costs or efficiencies can be held constant; therefore, it usually becomes necessary to specify that the figure of merit be some criterion such as: "cost per target destroyed," "cost per vehicle expended," or "cost per accomplished mission." But it is precisely this point at which difficulties creep in. What costs are to be used? How are these costs separated for the different parts of the system? Since the costs of each system component will vary with the total number produced, what is the desired rate of production or stockpiling; what is the rate at which these units should be used in testing and training; and, what is the final number to be stockpiled?

For example, if a weapon is to be used strategically or tactically for an indefinite period of time after the outbreak of a war, it would be desirable to base the measure of system merit on the "cost per mission accomplished," or similar criterion. However, in the use of this measure, the initial testing, training and continuous upkeep costs must be amortized in some manner. Alternatively, if it is decided that the weapon systems being compared will have utility only for a fixed period during the war, it may be possible to estimate a "campaign cost" on the basis of the total number of targets, the survival probability, the system reliability, stockpiling and training costs, and the duration of the campaign.

This digression on figure of merit should illustrate that the role of judgment and experience is probably of prime importance in setting up procedures for carrying through an analysis. At present there are no universally applicable procedures; and, furthermore, it appears that there never will be any.

Although, for obvious reasons, cost is generally acceptable as a common factor in the measurement of system merit, it should be borne in mind that it is only one of a number of important factors. For example, additional skilled manpower is sometimes unobtainable, so that, within a reasonably small varia-

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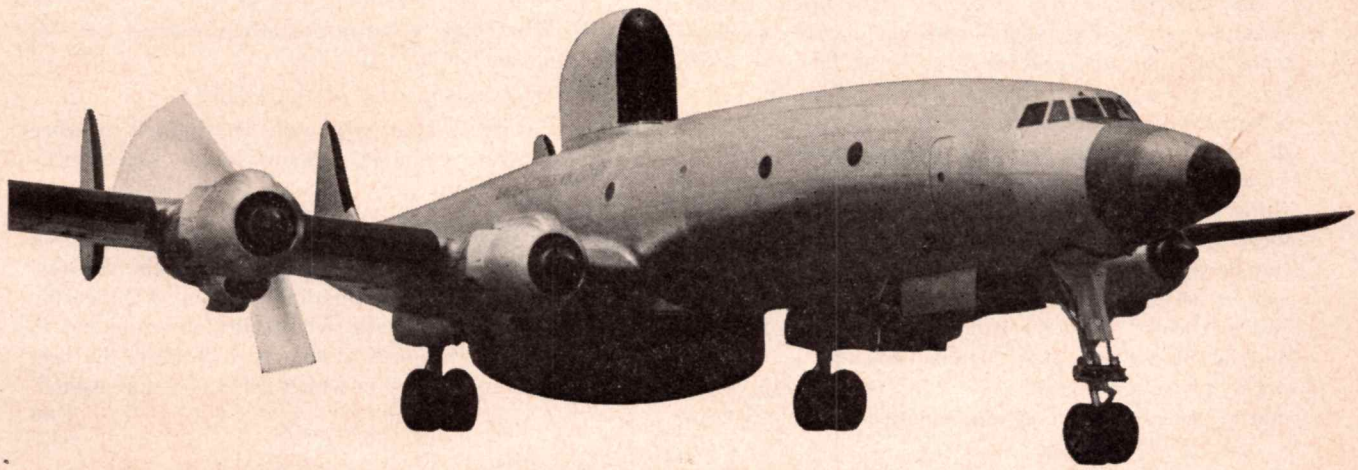

tion in costs, that system might be most suitable which requires fewest skilled men.

Having established a method for measuring system cost (for any other quantity decided upon) one proceeds to a similar investigation of system efficiency, not to be confused with "effectiveness." It might be a reasonable first try to use as an efficiency measure the number of targets destroyed for a given expenditure of vehicles. But the same general caution applies here as applies to cost. How are these vehicles deployed? Singly? In groups? Are any evasive tactics to be included in the flight path? Such tactics will introduce a change both in vehicle survival and system effectiveness.

Figure 2 illustrates the interdependence of these factors. One block, "vehicle type," is illustrated in greater detail than the others but it should be understood that within each of the blocks, such as "ground support system" and "logistical supply system," is a similar set of interrelated factors that will affect the overall system efficiency and system costs, as well as the system merit.

Alternate ground and supply systems all have to be considered in the light of their vulnerabilities and reliabilities as well as their costs. Above- or underground operation, dispersal of bases, revetment construction, use of camouflage, and mobility are items that must be covered in the discussion of an operational concept to provide at least a qualitative feel for the relative vulnerability of this system as compared with other proposed systems. Similarly, method of vehicle and storage transportation, vehicle sectionalization, storage or transportation of fuel, type and number of ground vehicles to be employed in the operation must be carefully spelled out in order to provide an understanding of the comparative reliability. It often occurs that, failing any quantitative measure of the reliability and vulnerability of alternative systems, the analyst makes a choice among these systems entirely on the basis of this qualitative "feel": another instance of the importance of judgment and experience.

As stated previously, in Figure 2 the block labeled "vehicle type" is expanded somewhat in order to illustrate the interrelationships of several factors. Performance factors of range, speed and altitude are either explicitly or implicitly fixed by the demands of the GOR. (Note that the arrows connecting "vehicle weight" with other factors are directed both ways to show the mutual dependence of these factors.) But these factors also affect the number of targets that can be reached, and the vehicle's survival probability against an enemy defense system. Similarly, accuracy and warhead type are related to the degree of target destruction achievable with each vehicle.

Having established the mode of measuring system merit, one can set up a mathematical model that includes these factors and that leads to a numerical value. Available techniques naturally include all the tools of mathematical analysis, the calculus of probability, and numerical computations with mechanical aids. To predict the effects of physical variations that culminate in errors at the target, hence a lower probability of target destruction, the engineer sometimes uses techniques from noise or filter theory, and these take into account the guidance equations, the vehicle's overall response and errors resulting from system noise and radar glint. Having established the probable miss-distances, one can proceed to estimate the probability of target destruction by taking into account the yield and type of warhead, (remembering the probability that the warhead will operate correctly) the target "hardness," and the dispersion and sizes of targets.

From such an analysis, really a chain of analyses, one arrives at a working assumption of the type vehicle to be used and an operational concept for the entire system. More specifically the following questions are answered:

1) What kind of weapon is recommended? What are the major functional features of this weapon?
2) What are the speed, altitude and range capabilities of the missile or aircraft?
3) What is the simplest guidance system that will satisfy accuracy requirements?
4) What is the best warhead? Or, what is the recommended range of variation in warhead size or type?
5) What is the most reliable mode of operation for this warhead?
6) What is the operational concept along which the entire weapon system is designed?
7) What are the major functional requirements of the ground support system and the training system?
8) What ground-based equipments are required, and how many of each type? What kind of supporting ground or air vehicles are required, and how many of each type?
9) Can this system operate from existing airfields or bases? Are any special facilities required, and if so, what kind and how many of each?
10) What type of transportation systems are required?
11) What is the cost of the system?
12) Can the system ultimately be adapted to other uses, for example, reconnaissance, target practicing?

In conclusion it should be stressed that the weapon system characteristics arrived at through the analysis are a first-order approximation, and a considerable amount of effort is required in later development to ensure that the ultimate system is, in reality, the best possible for the period in which it is to be operational.

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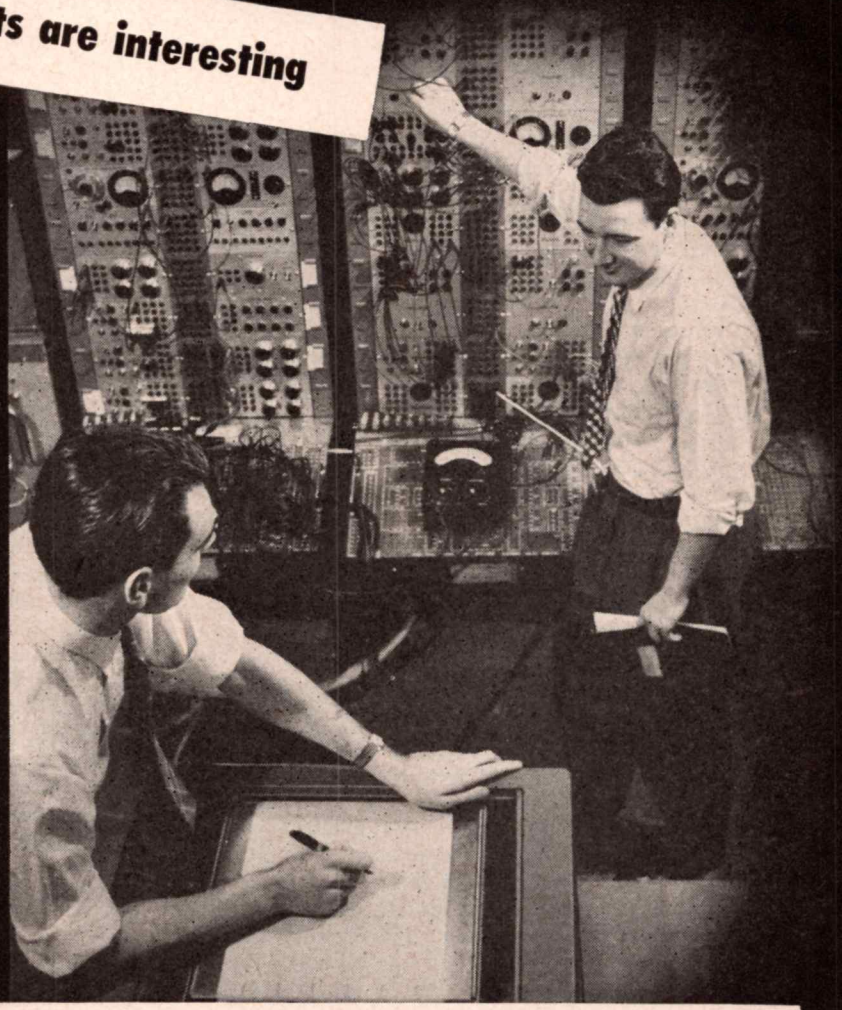

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Careful selection of materials coupled with combination cooling yields satisfactory results in combating aerodynamic heating problems.

Designing for HIGH-SPEED MISSILE COOLING

R. H. HEPPER
Project Group Engineer
McDonnell Aircraft Corporation
St. Louis, Missouri

AERODYNAMIC HEATING of a structure in a supersonic or hypersonic missile is caused by friction between the skin of the missile and the adjacent boundary layer. This article briefly covers ways of minimizing elevated temperatures by insulating and cooling and by various other design methods.

Materials with high emissivity radiate heat away from a structure and keep its temperature down. Many materials can be coated to give them a high emissivity; stainless steel has an emissivity of 0.40 to 0.50, but when the surface is oxidized it increases to 0.80.

Although insulation by itself will usually only reduce heating rates, there are many applications where insulation is a valuable aid. A combination of insulation and cooling will usually be much more efficient than cooling alone. For transient heating conditions, the insulation will delay the structure from reaching a critical temperature until the heat input is reduced or the missile has accomplished its mission.

Various coatings can be applied directly to the metal skin to act as an insulator. Certain oxide coatings show promise. A maximum temperature drop of 1500°F through 0.010 inch aluminum oxide coating has been recorded. This is an extreme case, but it shows what can be accomplished.

A nonstructural outer shell has many advantages. Although the outer shell would get hot, it has to carry only the local airload and can be attached so that the shell is free to expand. The outer skin can be a radiation shield with a high emissivity outside and a low emissivity inside in order for the shell to radiate the heat away from the structure. Some form of blanket insulation can be placed between the radiation shield and the structure to reduce further the heat flow. The outer shell can be made more effective by using a radiation shield, insulation, another radiation shield, and then an air gap, to attain the desired insulating effect.

In the fuel tank area, if fuel is in contact with the skin, it will keep the skin cool. But it is also necessary to keep the fuel cool. One approach to this problem is to trap fuel next to the skin; the fuel will vaporize and act as an insulator. One way this can be done is by having a mat next to the outer skin which will absorb fuel, and then as the skin heats up the mat will trap the bubbles of gaseous fuel. Another way is to have an inner shell in the fuel tank as shown in Figure 1. The fuel between the skin and inner shell is vaporized and trapped. The longer the lengths of each section of inner shell, the greater the pressure differential it will have to withstand. The gas pressure will be the same throughout and equal to the liquid pressure at the bottom of each section. The method shown in Figure 1 is applicable only during a vertical climb.

• • Transpiration Cooling, Surface Melting

On a hot dry day the cooling effect due to evaporation of perspiration is inevitable. This same principle, known as transpiration cooling, can be used to cool the skin of a missile. A fluid is pumped through a porous skin and cools the surface that it is being forced through and also the boundary layer. The boundary layer would be cooled not only in the immediate area but also some distance aft, so that normally only the hot nose of the body or the hot leading edge of the surfaces would have to be porous. Possible materials for this application are wire cloth or porous sintered materials, with the wire cloth showing better strength properties at present. A coating can be applied to the porous material which will melt at some predetermined temperature, in this way starting the transpiration cooling only after a critical temperature is reached. Experiments are being run using steam as the cooling fluid.

Another way of cooling the surface of a missile is to allow a coating to melt and absorb heat in the process. The coating serves as an insulator for the structure until the melting temperature of the coating is reached and then starts absorbing heat during the melting process.

Table 1—Potential Nose and Leading Edge Materials.

MATERIAL	MELTING TEMPERATURE	NOSE TIP TEMPERATURE	FIN LEADING EDGE TEMPERATURE
HAFNIUM CARBIDE	7000°F	3790°F	4740°F
TANTALUM CARBIDE	7000°F	3790°F	4740°F
ZIRCONIUM CARBIDE	6400°F	3790°F	4740°F
TITANIUM CARBIDE	5700°F	3790°F	4740°F
TUNGSTEN CARBIDE	5200°F	3790°F	4740°F
MAGNESIUM OXIDE	5100°F	5130°F	6040°F
ZIRCONIUM OXIDE	4900°F	4290°F	5450°F
BERYLLIUM OXIDE	4500°F	4600°F	5580°F
SILICON CARBIDE	4200°F	3790°F	4740°F

The maximum allowable temperature for guidance equipment, warheads, hydraulic actuators and other equipment is considerably lower than that of the structure. These can be cooled by refrigeration-type systems, water-cooling or a combination of both. Water-cooling is usually more efficient at higher temperatures. The water is circulated, absorbing heat from the equipment. The hot water is then expanded, which results in a small portion vaporizing and the rest being cooled. The cooled water is then recirculated and the cycle repeated. Another way of cooling with water is to spray it directly on equipment components.

Cooling the skin by circulating water does not look too promising. The weight required to cool the skin is normally more than that required by the loss of structural efficiency at the elevated temperature.

● ● Structure at Elevated Temperature

Flight at elevated temperature adds another dimension to the job of the structure's engineer — the dimension of time. A structure at elevated temperature will fail under any load when given enough time. The structure must not only be designed to withstand various loadings but also must be designed for a certain flight life. Loads must be considered as two basic types: the short duration (such as maneuver and gust loads) for which time is of little significance, and the essentially steady state loads (such as nominal flight attitude or internal pressure) which are time dependent. The load spectrum should be known and ways of analyzing its effects should be available.

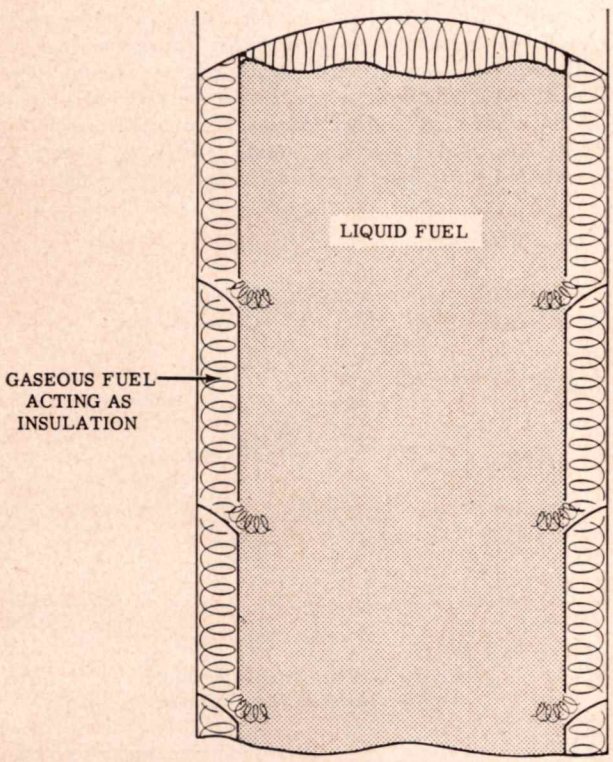

Figure 1—Fuel tank insulation using inner shell construction.

The strength and stiffness of materials decrease with increases in temperature and exposure time. Although numerous tests have been performed on materials at elevated temperature, information is generally lacking for very short times and high heating rates, and at the higher temperatures.

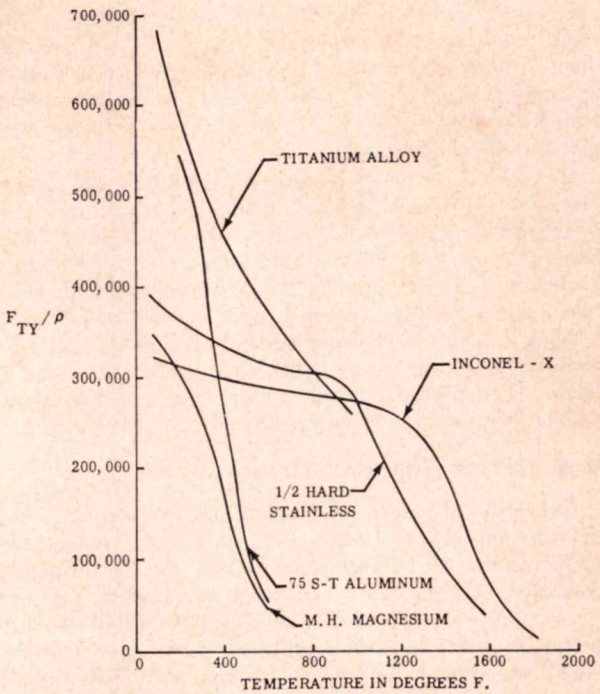

Figure 2—Strength efficiency at elevated temperatures. Time, 30 minutes.

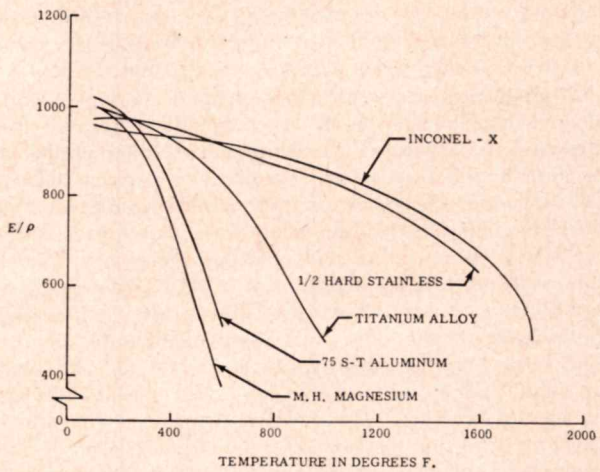

Figure 3—Stiffness efficiency at elevated temperatures. Time, 30 minutes.

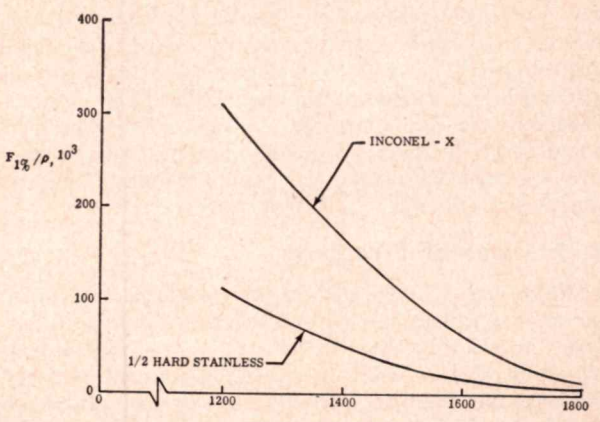

Figure 4—Creep efficiency at elevated temperature. Time, 30 minutes.

Selecting materials that are structurally efficient at elevated temperatures is important. A plot of yield strength divided by density versus temperature is shown in Figure 2, and modulus of elasticity divided by density versus temperature in Figure 3. Figure 4 shows the same type plot for one percent creep.

If buckling is an important consideration, the above plots may be misleading and a buckling efficiency curve is needed to complete the picture. It should be remembered that one plot will not hold for all types of buckling problems, but rather the factors involved and their relative significance must be considered for each case. Figure 5 shows a buckling efficiency curve for a thin skin cylinder stabilized by internal pressure and subject to bending loads. The lighter metals retain their usefulness to higher temperatures when buckling is the criterion.

● ● Creep, Thermal Stresses

Currently, there is no method for calculating creep deformations due to various combinations of loading and temperature. It is necessary to test for each specific condition. Various tests have been run, cycling the load or the temperature, but the results vary widely for different materials and test conditions. Tests on some materials have shown that the cycles can be added directly to give the cumulative effect, while in other cases the cycling greatly accelerates the creep effect; and in still other cases, cycling slows down the rate of creep. Information on the creep of complex structures is also lacking, but it appears that creep can be avoided as a serious problem within the expected lifetime of most missiles if given proper design consideration.

Thermal stresses result from unequal thermal expansions being induced in a structure either because the structure is subjected to temperature differentials or because of differing coefficients of thermal expansion in the structure. Temperature differentials result when a missile is being heated due to rapid acceleration, or when the missile is in a dive and entering denser air. Under this transient heating condition, the skin heats up more rapidly than the substructure. This results in inducing compression in the skin and tension in the substructure. The force that the substructure exerts on the skin will be equal and opposite to the force that the skin exerts on the substructure. This force is a result of the difference in deflection between the actual deflection of the component and the amount it would deflect if it were not restrained. If rigid attachments are assumed, both components will deflect the same amount, which will result in a simple but conservative solution. For a more accurate answer the flexibility of the attachments must be considered. The thermal stresses must be added to the flight load stresses in computing buckling, but can usually be disregarded in estimating ultimate failure: the deformations required for failure may be very large when compared to the thermal deformations, and extreme thermal stresses cannot be maintained for any length of time because of plastic and viscous deformation.

● ● Types of Structure

Major causes of thermal stresses are local heat sinks; therefore a monocoque construction has a definite advantage. An efficient structure for a high-speed missile body is a thin skin cylinder stabilized by internal pressure. However, too high an internal pressure not only causes a difficult sealing problem but results in excessive creep at elevated temperature. This type structure requires special handling techniques.

Another construction that minimizes thermal stresses is a thick skin structure, but this may result in a sizable weight penalty. Integral stiffened skin may be a promising compromise because the thermal stresses are less than in standard sheet stringer construction and the weight penalty is not as prohibitive as in unstiffened thick skins.

Other monocoque structures showing promise are the various sandwich constructions, especially honeycomb constructions. These would also have favorable insulating properties.

The difference in temperature that exists along the body of a missile or the chord of an aerodynamic surface is another cause of thermal stress. Figure 6 shows a typical temperature distribution along the body of a hypothetical missile at the end of the climb phase at a velocity of 10,000 feet per second and at an altitude of 120,000 feet. The skin is 0.020 stainless steel. It will be noted that the temperature at the nose tip is much hotter than the rest of the body. The same will be true of the leading edge of an aerodynamic surface. The hot leading edge will expand more than the rest of the surface, possibly causing the leading edge to buckle or the entire surface to twist. This latter effect may reduce the torsional rigidity of the surface to below flutter requirements.

Because the hot leading edge tends to expand more than the rest of the structure, it may be desirable that it be articulated. A slotted leading edge leaves room for expansion; and by having small individual inserts, it greatly helps the handling problem because the materials

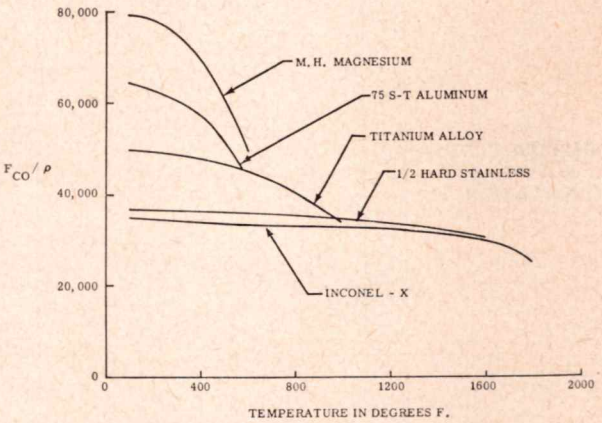

Figure 5—Buckling efficiency at elevated temperature.

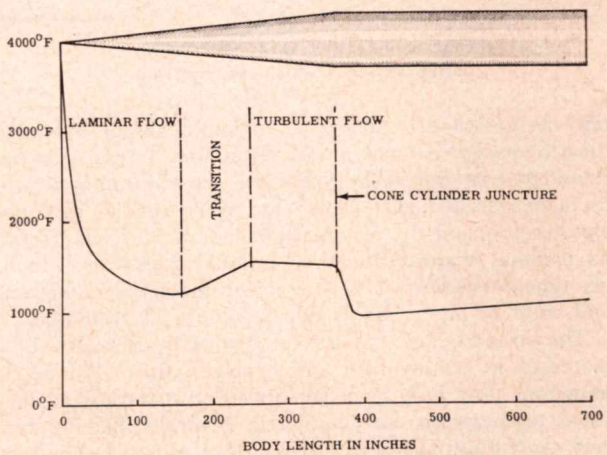

Figure 6—Temperatures along missile body.

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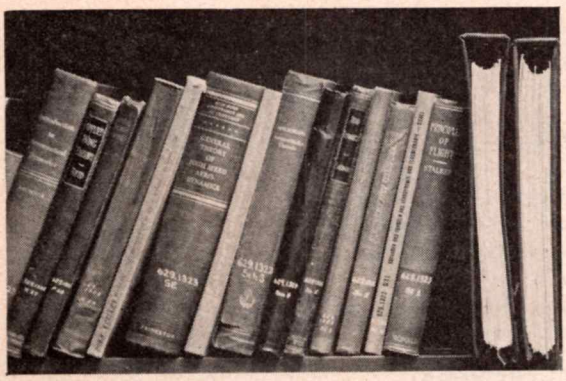

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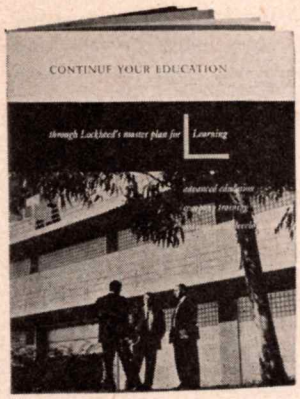

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that appear most promising are quite brittle at room temperature. Fortunately, these materials are relatively ductile at elevated temperatures. Figure 7 shows a possible design for a leading edge with inserts.

The sharper the nose tip or surface leading edge, the hotter it will be. Rounding these edges increases the drag; therefore the final choice represents a compromise between drag and feasible structural design. The leading edge temperature can also be reduced by increasing the angle of sweep on an aerodynamic surface.

The nose tip and surface leading edges will be at a much higher temperature than the rest of the structure. The leading edge of a missile aerodynamic surface traveling at Mach 10 could be above 5000° F, which is above the melting point of most materials. Fortunately, this a local condition, and materials such as carbides and oxides show promise for this application. The temperature attained will vary significantly depending on the emissivity and thermal conductance of the material selected. Thermal conductance must be considered as well as the maximum temperature that each material can withstand. Table I shows the melting temperature of several materials along with the temperature that would exist for a nose tip and fin leading edge for a condition checked. Tungsten and molybdenum show promise as nose tip and leading edge materials if oxidation resistance coatings are developed. Tungsten, for example, has a melting point of around 6000° F, but exhibits a volatile oxidation above 1100° F.

● ● Flutter

Flutter problems will be increased due to elevated temperature for many reasons, the most obvious being reduced stiffness due to a reduction in the modulus of elasticity. A buckled panel or even a panel in compression is more susceptible to panel flutter, and panel buckling is much more likely because of thermal stresses and reduced material properties at the elevated temperature. In addition, buckled skin panels reduce the effective stiffness, resulting in a more flexible structure which is generally a degradation to flutter. The reduced effective torsional stiffness due to a hot leading edge previously discussed will also aggravate the flutter problem.

A missile flying at an angle of attack will have a hotter lower surface than upper surface. In addition to causing thermal stresses, this situation will cause the lower surface to expand more, which will warp the structure and may increase the loading on it in a manner similar to that due to aeroelastic effects. A nonstructural outer shell may be required which would allow the hot lower surface to expand without critically warping the basic structure.

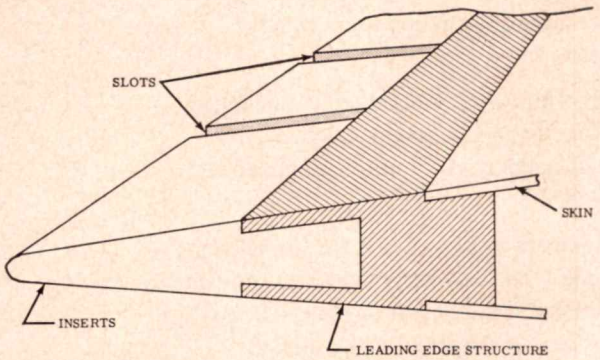

Figure 7—Slotted leading edge.

To keep thermal stresses to a minimum, materials with low coefficients of thermal expansion and high thermal conductance should be used. The use of materials with low coefficients of expansion result in lower stresses for a given temperature difference. With materials with high conductivity, the temperature difference will be held to a minimum.

Normally, the use of the same material throughout will result in the lowest thermal stresses; however, in some cases it may be advantageous to use different materials. If both parts of the clamp ring shown in Figure 8 are of the same material, the outer clamp will get hot faster and expand away from the rest of the structure leaving a gap. However, if the outer ring is designed so that it has a lower coefficient of expansion, the ring will stay snug during the transient heating phase. If an equilibrium temperature is reached during a later phase, stress analysis may indicate a high thermal stress, but the creep will generally be enough to prevent a failing stress from occurring. Under conditions of high temperature and high loading, creep will occur in a short time.

● ● Conclusion

A missile can be insulated from high temperatures by using a nonstructural outer shell or insulating coatings. It can be cooled by various methods including transpiration cooling. Materials that are structurally efficient at the elevated temperatures must be selected. Thermal stresses can be minimized by using monocoque constructions and articulated leading edges. Materials for the extreme temperatures existing at nose tips and surface leading edges must be tested to prove engineering ideas.

—End.

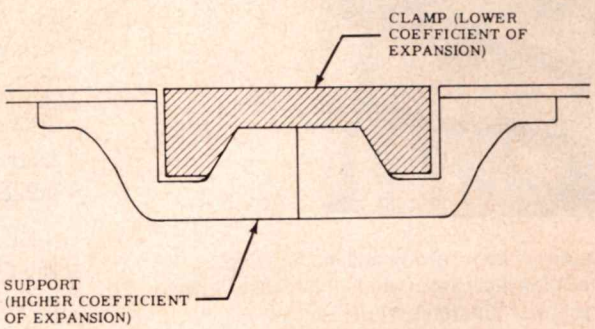

Figure 8—Clamp ring construction.

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Aerodynamic Heating

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2. *Analytical Studies of Aircraft Structures Exposed to Transient External Heating*—Volume I—*Thermal Response of a Thin Plate Under the Influence of a Constant Temperature Edge*, Alphonso Ambrosio and Takao Ishimoto, WADC Technical Report 54-579, University of California, Los Angeles, California, May 1954.
3. *Analytical Studies of Aircraft Structures Exposed to Transient External Heating*—Volume II—*Thermal Response of a Finite Plate and the Thin Plate Criterion*, Alphonso Ambrosio and Takao Ishimoto, WADC Technical Report 54-579, University of California, Los Angeles, California, November 1954.
4. *The Effect of Nonuniform Surface Temperature on the Transient Aerodynamic Heating of Thin-Skin Bodies*, A. E. Bryson and R. H. Edwards, Journal of the Aeronautical Sciences, July 1952.
5. *A Design Manual for Determining the Thermal Characteristics of High Speed Aircraft*, H. A. Johnson, M. W.

F-86 Saberjets and H-13 helicopter of the 15th Fighter Group, Niagara Falls, N. Y.

A MATTER OF *Minutes...*

Only minutes for U. S. Air Force interceptors to get in the air and on target . . . and minutes, too, for a Bell H-13 helicopter to be at the scene of a possible emergency.

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For further information circle Reader Reply No. 6

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Structural Test

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Creep

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new books

For further information circle number indicated under Trade Literature on Reader Reply Card — page 33.

INTRODUCTION TO PLASTICITY, Aris Philips, 1956, Ronald Press, New York. 230 pp. $7.

An introductory text about metal plasticity, written from the point of view of the stress analyst, the book includes chapters on the calculation of the collapse load, the moment-curvature diagram, bending with axial force, deflections, curved bars, stress-strain relations, collapse under combined stresses, and strain hardening under combined stresses.

Circle Reader Reply No. 96

MACHINE DESIGN, Joseph Edward Shigley, 1956, McGraw-Hill, New York. 523 pp. $7.75.

Part I constitutes a study of the design of fundamental machine members, such as shafts and machine frames; develops the basic design factors used in making engineering decisions such as stress, displacement and heat; and defines important concepts used in machine design, such as factor of safety. Part II applies the principles developed in Part I to the study of various design approaches to a group of common machine elements.

Circle Reader Reply No. 97

ASTM SPECIFICATIONS FOR STEEL PIPING MATERIALS, American Society for Testing Materials, September 1955, Philadelphia, Pa. 432 pp. $4.

The 1955 edition of this compilation sponsored by the ASTM Committee A-1 on Steel contains the latest approved form of 58 ASTM specifications for ferrous pipe, tubes, castings, fittings and bolting materials.

Circle Reader Reply No. 98

ROCKETS AND GUIDED MISSILES, John Humphries, 1956, Macmillan, New York. 229 pp. $6.

This book is intended in the main for those engineers who, while not engaged in the field, would like to obtain an overall picture of rocket motors and their applications, with particular reference to guided missiles. Emphasis has been placed on the general problems involved. The book is not intended as a compilation of the world's rockets and guided missiles.

Circle Reader Reply No. 99

MIRACLE OF WORLD WAR II, Francis Walton, 1956, Macmillan, New York. 575 pp. $7.50.

The present book tells the story of American war production — of nearly 200,000 large and small businesses, their managements, their employees, and how they produced between 1939 and 1945 war materiel with a value of $100-billion.

Circle Reader Reply No. 100

calendar

June 25-30—International Association for BRIDGE AND STRUCTURAL ENGINEERING, 5th International Congress, Lisbon, Portugal.

July 3-6—Conference on the PHYSICS OF NUCLEAR REACTORS, the Institute of Physics, London, England.

July 10-Aug. 9 — INTERNATIONAL AVIATION Exposition, Mexico City.

July 12-14 — Seventh International ASTROPHYSICAL Symposium on MOLECULES IN COSMIC SOURCES, Liege, Belgium.

Aug. 1-5—AIR FORCE ASSOCIATION annual convention, Roosevelt Hotel and Municipal Auditorium, New Orleans, Louisiana.

Aug. 3-5—Fourth Annual Fly-In of the EXPERIMENTAL AIRCRAFT Association, Oshkosh, Wisconsin.

Aug. 6-8 — AUTOMOTIVE ENGINEERS National West Coast Meeting, Mark Hopkins Hotel, San Francisco, California.

Aug. 15-17—IAS National TURBINE-POWERED AIR TRANSPORTATION Meeting, Grant Hotel, San Diego, California.

Aug. 21-24—Western ELECTRONICS Show and Convention, sponsored by IRE and West Coast Electronic Mfrs. Assn., Pan-Pacific Auditorium, Los Angeles, California.

Sept. 17-21 — Instrument Society of America, 11th Annual INSTRUMENT-AUTOMATION Conference and Exhibit (International), New York City.

Pictured above is just one example of Rohr-built Pow-R-Pax that have made Rohr famous around the world. In addition to the Convair 440 — Rohr builds the Pow-R-Pax for many other famous military and commercial airplanes including the Boeing KC-135, Douglas DC-7, and the Lockheed Super Constellation.

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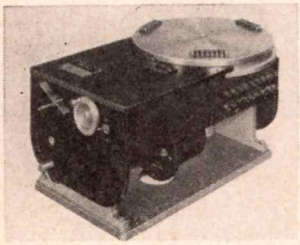
For further information use Reader Reply Card on Page 33.

Aircraft Fire Extinguisher. Small, lightweight extinguisher, designated the Stop-Fire AT-22-A, is the first hand portable fire extinguisher of the water solution type to be approved by Underwriters' Laboratories, Inc., for use in aircraft for control of incipient Class A fires. In contrast to existing hand portable water-type units which are cartridge operated and use plain anti-freeze water solutions as their extinguishant, this device is a stored pressure, loaded stream fire extinguisher. Extinguishant is a fortified anti-freeze solution which is non-toxic and on contact with fire will not produce injurious fumes. Withstands burst pressures exceeding 900 psi. Stop-Fire, Inc. (E-1)

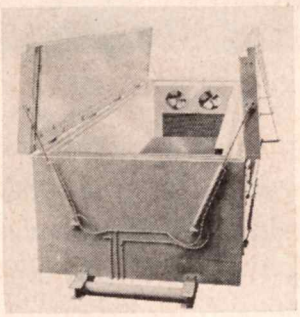
Transistorized Power Supplies. Universal Atomics Corp. announces development for the aircraft industry of a series of lightweight, completely transistorized d-c to a-c power supplies capable of delivering output from 24 to 28 v, and from 1½ to 6 v where required. Power supplies are available that give any combination of voltage and current requirements up to 10 w from as little as 6 v input in a 3-lb unit. Standard ambient temperature range is —25°C to 75°C. Range can be extended to —65°C to 125°C or more on special models. (E-2)

Unit Mount. Robinson Aviation, Inc. says its new all metal, lightweight unit mount, called K375, has been engineered for vibration protection of all airborne electronic equipment used in jet aircraft and winged missiles. Unit has frequency of 6-9 cycles/sec and vibration isolation efficiency is 90 percent at 30 cycles/sec and improves at higher frequencies. Tested plate-type design is especially adaptable to installations where small space does not allow use of other types of unit mounts or beams, according to Robinson. (E-3)



Rate-of-Turn Table. Small, lightweight instrument for calibrating and evaluating rate gyros is suitable for flight line testing in the aircraft as well as in the production line. Two ranges, 1° to 600°/sec (Model G347) and 0.1° to 60°/sec (Model S347), are available. Accuracy of setting and repeatability of new instrument is within 1 percent. Angular velocity is constant within approximately 0.25 percent, including cumulative drift, wow and flutter errors. Genisco, Inc. (E-7)

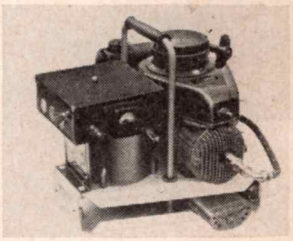
Aircraft Battery Substitute. Model KM75 operates from 115 V.A.C. 60 cycles single phase and provides a continuously adjustable output from 0 to 30 v d-c. Ripple is held to ½ percent at the maximum rated load current of 5 amp. Conforms to specification MIL-E-7894 as a power source for testing and operating aircraft electrical equipment and components. Mounts in a standard 19 in. rack and occupies 8¾ in. of panel height. Opad Electric Company. (E-8)



Conditioning Box. Designed for Aerojet-General Corporation, this new piece of testing equipment is so constructed that complete rocket motors can be lowered into conditioning box and then be subjected to extreme temperatures ranging from —100°F to 170°F in order to assure proper functioning. Temperature control tolerances are held at ±3°F in time and space. Unit measures 30 ft x 8 ft x 6 ft. Moore & Hanks Company and Pacific Refrigeration Company. (E-14)

Dry-Photographic Enlarger. RCA announces new type of dry-process enlarging printer capable of reproducing 15 standard size engineering drawings a minute from microfilm originals. This Electrofax machine has an automatic focus, reproduces standard A, B and C-size drawings in full scale and larger drawings in half size, and can be pre-set to reproduce up to 500 microfilm originals at one loading, with up to 24 multiple copies of each. (E-15)

Hydraulic Valve. Heavy-duty, two position, solenoid controlled unit is now in production by Sargent Engineering Corp. for use in missile launching systems. Operates on 95v-125v, 60 cycle, single phase, a-c power. Lapped, hardened rotor and sleeve assembly is of unique design and affords low leakage, insensitivity to dirt, low friction and low flow forces, according to manufacturer. (E-16)



Auxiliary Power Unit. Model 5903 series, part of a new line of small lightweight auxiliary power units just introduced by Lear, Inc., is a completely self-contained gasoline engine-driven generator package which supplies either 1350 w d-c power or 1500 w 400 cycle a-c power. Weighs less than 35 lb and is completely contained in a 1.5 cu ft package. LearCal Div. says it is particularly suitable for supplying power for aircraft electrical systems. **(E-20)**

Solenoid Toggle Switch. New miniature 3.6 oz switch, type CQ-31, has been designed for use in systems which require a visual "on-off" indication. Consists of a miniature microswitch which is actuated by a toggle that is held in position by means of a solenoid-operated detent. Bendix Aviation Corporation, Eclipse-Pioneer Div. (E-21)

Counting Mechanism. Counting speeds up to 20 counts/sec may be obtained on a new tallying device developed by Northrop Aircraft, Inc. The solenoid operated mechanism can add or subtract, the number of digits used being limited only by the amount of inertia the solenoids are capable of handling. (E-22)

Air Compressor Motor. New internally-geared air compressor motor with tested ability to withstand high shock loads is now being produced for aircraft duty by U. S. Electrical Motors Inc., Aircraft Div. Designated Type GA, the 22 lb motor operates continually on 3-phase, 400 cycle, 208 v a-c and has a takeoff speed of 3700 rpm. Delivers 3.5 hp at sea level, 2.5 hp at 50,000 ft. (E-23)

Axial Flow Blower. Motronics Corporation announces new compact blower claimed to move more air for its size than any other presently produced. Blower, which can be used to cool aircraft electronic components, has

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For further information circle Reader Reply No. 17

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PM-8001-2 assy.	7900-573265 75	5/8" to 23/32"
PM-8001-3 assy.	7900-573266	13/16" to 29/32"
PM-8001-4 assy.	7900-573266-25	31/32" to 1 1/16"
PM-8001-5 assy.	7900-573266-5	1 5/32" to 1 1/4"
PM-8001-6 assy.	7900-573266-75	1 11/32" to 1 7/16"
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PATTON
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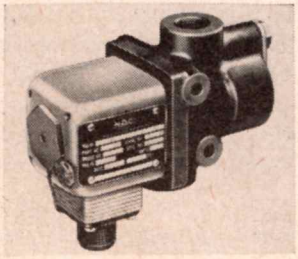
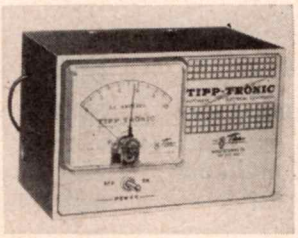
For further information circle Reader Reply No. 20

2.2 in. diameter, is 3 in. long and produces 60 cu ft of free air per min. (E-24)

Hollow Aluminum Bar Stock. New mill product developed by Harvey Aluminum, a wrought alloy named 6066, averages less than half the weight of a comparable size in solid aluminum bar. General characteristics of 6066, according to manufacturer, are excellent machinability, superior corrosion resistance, high strength and excellent finish. Readily machined on any type of equipment, new hollow aluminum stock can be obtained without tooling charges in standard round bar in a range of sizes. (E-25)



Pneumatic Shut-off Valve. Designed for application in aircraft, weapon, missile or industrial pneumatic systems, new d-c solenoid operated pneumatic shut-off valve, Model 21A, is now available in normally open or closed versions with or without manual override. Features statically balanced valve and sealing members of stainless steel and teflon and some with media nylon. Pressure ranges to 300 psi, temperature range —65°F to 275°F. National Aircraft Corporation. (E-28)

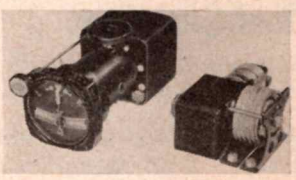


Safety Controller. New automatic controller, which provides warning and prevents damage from abnormal load conditions of any kind on electrically driven conveyor systems, is announced by Tipp Manufacturing Co. Called the Tipp-Tronic, device eliminates need for shear pins, slip clutches and other mechanical safety devices. (E-30)

Adapter. Dual drive adapter which provides two gear ratios from the same power source is announced by F. W. Stewart Corporation for use in conjunction with flexible shaft drives where more than one unit is to be driven from same power source. (E-31)

Metal Testing Kit. Contains all necessary solutions to identify numerous metals and their alloys. Results can be obtained in less than two minutes, according to Spot-Testers, Inc., and there is enough material for hundreds of tests. Manufacturer says kit is particularly useful for non-destructive identification of metals in machine parts and processing equipment. (E-47)

Liquid Polymer for Hermetic Sealing. Methods Development Group at Torrance facility of Douglas Aircraft Company has developed new method of molding-in-place hermetic seals based on Thiokol liquid polymer compounds. Seals are for electrical wiring passing thru bulkheads that must withstand critical pressure and temperature differentials. Technique consists of passing wires thru opening of bulkhead and then injecting Thiokol liquid polymer-based compound into hemispherical plastic molds around the wires to form seals. Thiokol liquid ploymer is a solventless liquid that converts entirely to a rubber at room temperature without shrinkage. Thiokol Chemical Corporation. (E-48)



Autopilot. New single-axis autopilot, called DART I for its function to control direction and rate of turn, consists of only two components—a turn sensing unit and an actuator—connected by a single cable. Air Associates, Inc., Aviation Supplies Div. (E-50)

Compass. Gyro-slaved directional system, designated Type MA-1, features

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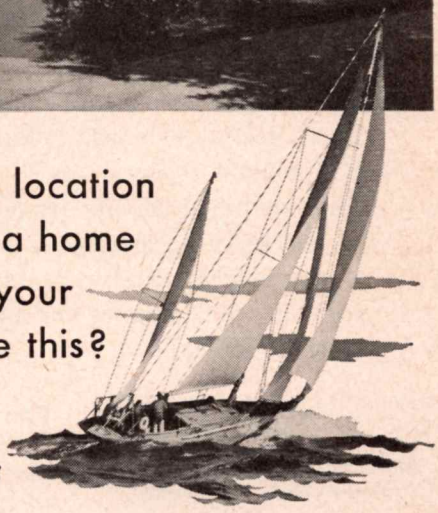

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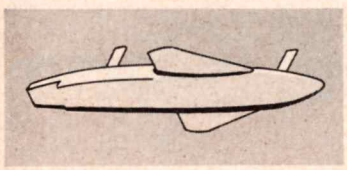
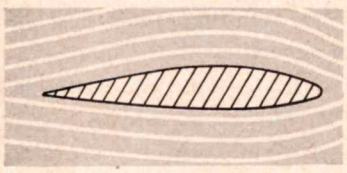


Pantobase—When designed into an aircraft the Pantobase system enables the plane to land and take-off from many types of surface without changes or additional landing equipment.



BLC-Boundary layer control as developed by Stroukoff increases the effective lift and delays stalling of the wing, thereby reducing required speeds and distances for take-offs and landings.

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WEST TRENTON, NEW JERSEY

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multiple indicators which can provide course readings at up to three different remote locations in the aircraft. Wherever magnetic readings become unreliable, MA-1 may also be operated purely as a gyro directional system unaffected by the earth's magnetic field. Lear, Inc., Grand Rapids Div. (E-51)

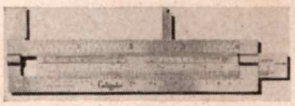
Tracing Vellum. Called Blutex, vellum is treated with 100 percent synthetic resins rather than oils, which permits faster and cleaner erasures, according to Frederick Post Company. (E-52)

Mounting Components Kit. Appropriate components provided for assembly to test, correct and prove design of a control system, computer sub-assembly, motor drive, gear train, or any other set-up requiring a combination of electrical and mechanical components. Servo Corporation of America. (E-53)

Cellular Plastics. LOCKFOAM, family of gas-expanded, foamed-in-place, cellular plastics developed by the Nopco Chemical Company has numerous applications in aircraft industry. Can be used as core material in radomes and as reinforcing material for aircraft parts. (E-54)

Sine Switch. Designed primarily for use in instruments, aircraft, and snap-acting relays where it can be installed within the housing of control, C9175 Klixon sine switch shows no significant change in operating characteristics between —65 °F and +285 °F Spencer Thermostat Div., Metals & Controls Corporation. (E-55)

Valves. New line of selector valves in the 0 to 1000 psi pressure range give "no leak" service in their indexed position in most fluid services, according to Republic Manufacturing Company. Recommended for air, gases, hydraulic oil, non-aromatic fuel, petroleum and water services. (E-56)



Caliputer. Pocket-sized, stainless steel instrument combines functions of a slide rule vernier caliper and vernier depth gage and computer in a single unit. Provides direct readings of circumferences and cross section areas and will multiply, divide, find squares and square roots caliputer. (E-57)

Gamma - Radiation Detector. Pocket-type device, called a dosimeter, measures up to 600 roentgens of gamma radiation. Technically known as Radiacmeter IM-93, this pen-type instrument provides a constant check on radiation exposure from atomic blast or fall-out. The device uses a quartz filament fiber about 1/10 the diameter of a human hair. Fiber is activated by the electrical charge stored in a unique aluminum and plastic capacitor. As gamma rays penetrate instrument the quarta fiber indicates total amount of radiation to which wearer has been exposed. Bendix Aviation Corporation. (E-5)

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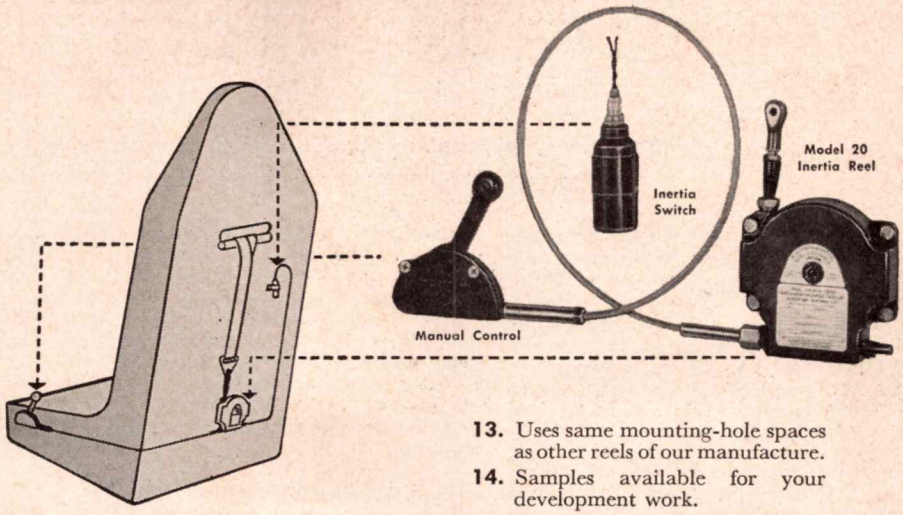

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For further information circle Reader Reply No. 22

trade literature

You may obtain copies of booklets and pamphlets below by circling the appropriate number on the Reader Reply Card on page 33.

Computer Kit. 4 pp bulletin describes an inexpensive (under $700) electronic analog computer in kit form being introduced by Heath Company. Claimed to be an advanced "slide rule" that permits engineering and research personnel to simulate electronically equations or physical problems, thereby saving many hours of calculation and experimentation. (T-1)

Miniature Altitude Switch. Specifications on new miniature barometric pressure switch, model GB-300, are now available from Aircraft Control Div. of Gorn Electric Co., Inc. Manufacturer says unit gives instantaneous automatic control of aircraft electric or electronic circuits and permits maximum control at all times, under all temperature and altitude conditions. Can be pre-calibrated to automatically open or close a circuit at any altitude from 1000 to 50,000 ft. (T-2)

Report on Contour Machining Conference. With over 500 engineers participating, conference accented improvements in aircraft and instrument fabrication, necessitated by difficult-to-machine designs, closer tolerances, larger contoured parts, new and harder metals. Report on First Annual Contour Machining Conference contains 24 pp of recent developments of tracer-controlled production methods. True-Trace Corporation. (T-3)

Receiving Tubes Chart. Quick-selection chart, ETD-1163-A, listing General Electric's 600-milliampere series-string receiving type tubes — all of controlled heater warm-up design — classifies the 48 tube types according to elements; lists typical service, heater voltages, maximum plate and screen dissipation ratings; and gives average characteristics. GE Tube Department. (T-4)

Resistance Welding at Work. Vol 4, No. 8, 8 pp illustrated publication discloses how Grumman Aircraft Engineering Corporation designed and resistance welded the integral leading edge, wing fuel tank for the U. S. Navy's F9F-8 Cougar Jet. Sciaky Bros., Inc. (T-5)

Impacts. 32 pp illustrated booklet discusses unique design possibilities of impact extrusion process and gives many examples of Alcoa impacts. (T-6)

Coil Winding Machines. 62 pp illustrated catalog No. 56 describes 42 coil-winding machines. Virtually all types of coils may be wound on the various models, according to Geo. Stevens Mfg. Co., Inc. Also includes page of time-saving, helpful winding formulas. (T-7)

Cemented Oxide. Technical report GTO-130, released by Carboloy Dept. of General Electric, gives latest information for applying cemented oxide tool materials. Covers Carboloy's initial grade 0-30, describing tool holders required, metals machined to date, and tooling information such as cutting angles, chip control, cutting speeds and feeds, coolants and regrinding. (T-8)

Hydraulic Pump. Product Data Sheet No. 5-47 discusses Lear-Romec Model RG-15000 rotary gear, positive displacement aircraft hydraulic oil pump. Lear, Incorporated, Lear-Romec Div. (T-9)

Engineering Data. 24 pp, new edition of National Machine Products Company's Engineering Data Section covers 14 topics concerning the technique in manufacture and proper installation of their product. Includes guide chart for calculating wrench torques. (T-10)

Servo Amplifier. Brochure describes Model 1800-0100, miniaturized, hermetically-sealed, plug-in transistor servo amplifier, primarily intended to receive signals from a Synchro Control Transformer and to operate a Kearfott Type 422185 Servo Motor or equivalent. M. Ten Bosch, Inc. (T-11)

Resistors Chart. Gives electrical and mechanical characteristics of Stackpole variable composition resistors. Illustrations and specifications for over 18 basic single and dual-section controls are shown with a tabulation of all possible modifications available on each control. Stackpole Carbon Company, Electronic Components Div. (T-12)

Low-Voltage Electrical Distribution Equipment. 160 pp, illustrated catalog GEC-1032A provides reference for products manufactured by General Electric's Trumbull Components and Distribution Assemblies Departments. Designed as source of information for specifying electrical power distribution equipment and components for applications up to 600 v. (T-13)

Wire Rope Assemblies. 24 pp illustrated bulletin TL 500 contains data on construction features, applications and breaking strengths. Describes complete range of Tru-Loc fittings and Tru-Loc wire rope assemblies. American Chain & Cable Company, Inc. Wire Rope Div. (T-14)

Limiters, Fuses and Specialties. Catalog presents detailed data on Sightmaster Corporation's line of small dimension limiters and fuses. Range of fuses encompasses sizes from ¼ in. x ⅝ in. to 13/16 in. x 10 in., in ratings up to 10,000 v. (T-15)

Electrical Tapes. 12 pp illustrated booklet gives technical data, characteristics and performance specifications to help users select the type of electrical tape best for insulating and protecting applications. Johns-Manville Sales Corp., Dutch Brand Div. (T-16)

Capacitors. 5 pp bulletin provides complete information on construction features and operating characteristics of new line of low-pass feed-thru suppression capacitors available from Filtron. According to the company, this is the first time a complete line of both 5 and 10 amp sub-miniature feed-thru capacitors have been available for commercial and military applications. Filtron Co., Inc. (T-17)

Lockbolts. Illustrated 4 pp folder TCL-111 gives application procedures for lockbolts for the aircraft industry available from the Cherry Rivet Div. of Townsend Company, and provides information on the guns used to install lockbolts. (T-18)

Microwave Tubes and Components. 6 pp folder gives partial listing of tubes and components available from Bomac Laboratories, Inc. Includes specifications for TR, ATR, Pre-TR and attenuator tubes, special shorted TR and ATR tubes, dual and triple TR and ATR tubes. (T-19)

Ball Bearings. 30 pp illustrated technical reference manual and catalog on small precison instrument ball bearings available from New Hampshire Ball Bearings, Inc. Stresses such considerations as types of bearings available, materials, components, engineering standards, tolerances and the computation of dynamic and static loads. (T-20)

Spot and Projection Welders. 8 pp illustrated bulletin 335-1 describes Sciaky Type SPT 1 spot welder and the EPT 1 projection welder. Both machines are air operated, press type, patented Three-Phase, and designed to cover a wide range of commercial welding applications. Machine data is tabulated to indicate KVA range, throat depths, welding capacities and electrode forces. Sciaky Bros., Inc. (T-21)

Fluorocarbon Inks. Problem of labelling, coding or otherwise marking surfaces of materials that resist conventional printing methods is nearing solution with new high temperature resistant, chemically resistant fluoro-

carbon type pigmented inks, according to The M. W. Kellogg Company. 4 pp brochure describes properties, methods of application and uses of these inks. KEL-F printing inks adhere to nylon, fluorocarbon and polythylene surfaces and can also be used for marking a wide variety of rubbers and other plastics, including rigid and plasticized vinyls. (T-22)

Dual Control Panel. Product Data Sheet No. 2-89A discusses Lear-Romec Model RR-15030-A, which is used in conjunction with Model RR-15020-A dual pressurizing unit for remote control and sensing of operation of radar air pressurizing equipment in aircraft. Lear, Inc. (T-23)

Adhesives, Coatings and Sealers. 14 pp booklet lists, in file type form, U. S. Government specifications for wide variety of adhesives, coatings and sealers. Includes specification cross-reference section listing recent changes in specifications designations to aid in correlating old and new specification numbers. Minnesota Mining & Manufacturing Co. (T-24)

Air Devices. 4 pp illustrated circular No. 587 describes line of Lunkenheimer Co. air devices, specifically designed to eliminate air leaks. Gives dimensions and pressure requirements. (T-25)

Gyros. Bulletin No. 380 gives specifications and characteristics of compensated vertical gyros, fully floated gyros and directional gyros available from Norden-Ketay Corporation. Also includes miniature precision potentiometers and dual sine-cosine potentiometers. (T-26)

Noise Measurement Instruments. Waveline, Inc. brochure discusses new microwave noise generating and measurement instruments designed to facilitate sensitivity tests on such equipment as receivers, traveling wave tubes, crystals. (T-27)

Voltmeters. Illustrated catalog VM-106 shows Trio Laboratories, Inc. line of miniature, panel-mounting vacuum tube voltmeters. Both a-c and d-c models are described for commercial or military applications as is new, low-level d-c VTVM designed to meet military specifications. (T-28)

Electro-Mechanical Assembly Kits. 15 pp brochure, TDS 1110, provides full information about the complete group of Servo Corporation of America's Servoboard electro-mechanical precision assembly kits, which have been completely revamped by the addition of new components. All parts may be purchased individually or as the basic, standard or master kit. (T-29)

Amplifier. 4 pp data folder gives voltage and current amplification information about new d-c amplifier suitable for most industrial and laboratory d-c measuring problems, according to Fielden Instrument Division, Robertshaw-Fulton Controls Company. (T-30)

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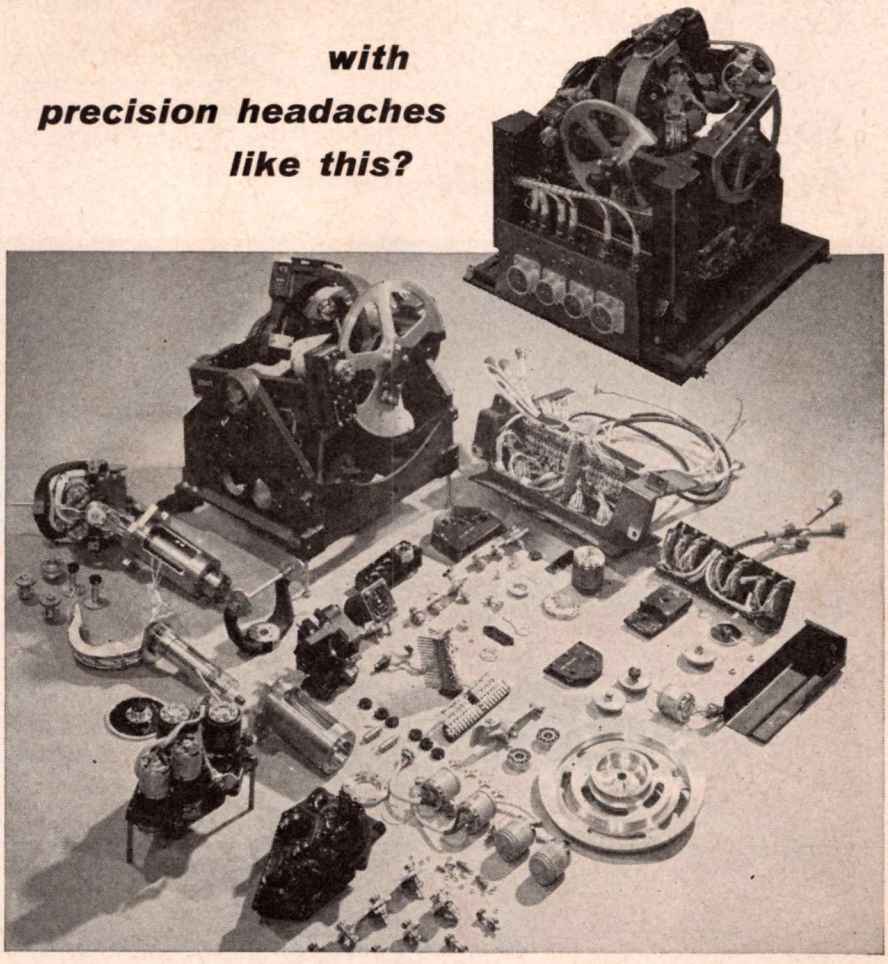

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abstracts

F. C. Holden and R. I. Jaffee, BETA TRANSFORMATION IN TITANIUM ALLOYS, TML Report No. 25, December 5,

Many of the problems encountered in the use of current titanium alloys may be related to beta-phase transformations. This report discusses the four principal types of transformations, the martensite, beta-to-alpha, beta-to-omega, and eutectoid, and presents data showing how these transformations are affected by such factors as alloy composition and thermal history. The application of this information to such fundamental problems as heat treatment and thermal stability also is discussed.

L. R. Jackson, MATERIAL PROPERTIES FOR DESIGN OF AIRFRAME STRUCTURES TO OPERATE AT HIGH TEMPERATURES, TML Report No. 38, March 23, 1956.

This report lists and discusses those mechanical and physical properties which may be of possible significance in the design of airframes which are to operate at elevated temperatures. These properties are evaluated on the basis of the precautions required to determine them accurately at elevated temperatures. A discussion is included on the availability of this type of property data.

Lee Arnold, DYNAMIC MEASUREMENTS IN WIND TUNNELS, NATO Advisory Group for Aeronautical Research and Development, AGARDograph 11, August 1955.

The state of the art of measuring unsteady aerodynamic forces and of testing dynamically similar models in the wind tunnel, both from the standpoint of dynamic stability and flutter, is presented. Model construction, instrumentation and scale effects are discussed. Accepted procedures developed in the various NATO countries are described and possible alternate procedures suggested.

STANDARD ATMOSPHERE—TABLES AND DATA FOR ALTITUDES TO 65,800 FEET. NACA Report 1235, 1955.

The physical constants and basic equations defining the International Civil Aviation Organization (ICAO) Standard Atmosphere are presented together with tables and diagrams of the properties of the ICAO Standard Atmosphere computed by the National Advisory Committee for Aeronautics in both metric and English units for altitudes from —5000 meters to 20,000 meters and from —16,500 feet to 65,800 feet.

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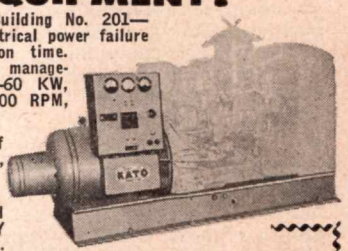

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(Aviation Engines)
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American Seating Co. (4) 61
Agency—Brooke, Smith, French & Dorrance, Inc.

Avro Aircraft Ltd. (5) 47
Agency—Cockfield, Brown & Co.

B

Bell Aircraft Co. (6) 53
Agency—Comstock & Co.

C

Cannon Electric Co. (7) 58
Agency—Willard G. Gregory & Co.

Cee-Bee Chemical Co. (8) 64
Agency—Ralph Yambert Assoc.

Chandler-Evans Co. (9) 13
Agency—Hugh H. Graham & Assoc.

Convair—A Div. of General Dynamics ..... Cover 4
Agency—Buchanan & Co.

D

Douglas Aircraft Co. 4
Agency—J. Walter Thompson

Douglas Aircraft Co. 59
Agency—J. Walter Thompson

F

Ford Instrument Co. (10) 43
Agency—G. M. Basford Co.

G

General Mills, Inc. (30) 63

Gladden Products Corp. (11) ..... Cover 3
Weir Publicity Assoc.

H

Harvey Aluminum (12) 20
Agency—Hixon & Jorgensen, Inc.

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K

Kato Enginering Co. (31) 64
Agency—Frizzell Advertising

L

Lockheed Aircraft Corp. (34) 51
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Lockheed Aircraft Corp. (33) 7
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M

Glenn L. Martin Co. (16) 9
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N

New England Mica Co. (19) 10
Agency—Wm. R. Andrews

P

Patton Mfg. Co. (20) 58
Agency—The Jay H. Maish Co.

R

Republic Aviation Corp. (21) 19
Agency—De Garmo, Inc.

Ralph C. Robinson Co. (22) 61
Agency—Chapin-Damm Adv. Agency

Rohr Aircraft Corp. 55
Agency—Barnes Chase

Rolls Royce (23) 16
Agency—The Wesley Assoc.

S

Sargent Engineering Corp. (24) ..... Cover 2
Agency—Darwin H. Clark Co.

Stroukoff Aircraft Corp. (25) 60
Agency—J. Wheelock Assoc.

P. A. Sturtevant (29) 61
Agency—Ross Llewellyn

T

Temco Aircraft Corp. (26) 11
Agency—McCann-Erickson Inc.

W

E. B. Wiggins Oil Tool Co. (27) 1
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EDITORIAL

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BRAVE NEW WORLD

IN ALDOUS HUXLEY's book "Brave New World," the author speaks of a group of workers called the gammas. They are given routine jobs to do, which they perform with distinction—if that term can be used in speaking of machine-like performance. Should a situation arise during the course of the job that calls for interpretation or evaluation, the matter is not considered for it is not stated in the job description. The work is carried on even though it may mean destruction of the final objective.

In this light, let us examine the gamma-like procedures of the Selective Service System acting under Major General Lewis Hershey's mandate that "In the long view practically every young man must expect to be called upon for some kind of service in the Armed Forces." We are particularly interested in the induction of men for the Six Months Critical Skills Program. Here, an engineer in 1-A can "volunteer" for six months' active duty followed by seven and a half years in the Reserve.

A local Selective Service Board is directed to induct a given number of men for the armed services. Physical and age requirements are prescribed. The Board automatically responds with a list of eligibles. In fairness, it should be noted that a token screening of critically-skilled men is made to see whether they are working in a defense-connected industry. But this procedure requires investigations, hearings, and all sorts of time-consuming and thinking operations. As of this past January, the work has been made easier and mechanical in order for the gammas more easily to take over. A Selective Service Board can place all its eligibles in 1-A. If a critically-skilled man does not fight this action, then he can elect to be placed in the Six Months Program, which is being used only by the Army. If he shows the bad manners to appeal his 1-A classification, then because of the fuss he created he is not eligible for the Program. And should his appeal fail, he goes into active duty for two years followed by three years in the Ready Reserve.

A high Selective Service official, when questioned about the Program, stated that a recent survey made by the Service showed that many deferred engineers are sitting in plush jobs. He implied that this was one of the reasons for the Program. When asked to produce the survey, the official hesitated, then stated that his remarks and the survey were "off the record," hinting that we should forget the whole thing. (We do not believe that we are bound by ex post facto "off the records," especially when the information is non-classified and is of the highest relevance to the health of our country.)

Keeping in view the dire need of this country for engineers and scientists, let us see what use the Army will make of a critically-skilled aeronautical man. First, he will be given eight weeks' basic combat training. This will be followed by two weeks' leave, and two weeks for assignment and travel. During the remaining fourteen weeks of the six months' period, he will be taught all over again the rudiments of his profession, which he is presumed to be proficient in—assuming, of course, that the Army has need of the engineer's specialty. If the Service has not, well, it must train him in something, so he receives either more basic training or is slotted perhaps into transportation because he has aircraft design experience.

When the six months' training is over, the engineer returns to his critical civilian job. Is he now allowed to pursue his work, unhampered by the Army? Not unless the Army says so. The man has seven and a half years' duty left to serve in the Reserve. He has signed a pledge that stated that if the Army desires, he will attend 48 weekly drills plus two weeks' field training, annually.

It would be interesting to figure out how many critical manhours are to be wasted in this fashion, and how many missiles and aircraft could be designed if the engineering talent were appropriately channeled.

If a war breaks out, do these engineers stay in industry where they can do the most good? Not necessarily! At the discretion of their draft boards the men are liable for induction. Do they go into the Air Force or Navy, who have programs that could possibly use these men? No! They go into the Army because that is the service that gave them their military training.

One last word on this situation comes from the Selective Service. They claim that aircraft companies have raised no objections to the Program; in fact, they are contributing lists of their engineers who can most readily be spared. Aircraft officials have replied unofficially by saying, "What would you do with a gun in your back? Either you cooperate and the engineer goes for six months. Or you don't, and he goes for two years. Should war come, and should the Army claim these men they've trained for military service, heaven help us all!"

Meanwhile, the gammas go about setting up their brave new world, seemingly unaware that they are at the same time destroying its architects.

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